

HOW IT WORKS ISSUE

VOL 3 ISSUE 8 APRIL 2014 ₹100

YOUR WORLD, DISSECTED

POPULAR SCIENCE

THE WORLD'S LEADING SCIENCE AND TECHNOLOGY MAGAZINE

INDIA

THE ELECTRIC RACECAR

THE NEXT GENERATION OF FORMULA ONE

A CURE FOR AIDS

CAN SCIENTISTS END THE EPIDEMIC?

EXCLUSIVE!

RADIO TECNICO

HOW A DRUG CARTEL TOOK OVER MEXICO—WITH WALKIE-TALKIES

PLANET EARTH (Yeah, we're not kidding)

SURGICAL SNAKEBOT PINK SLIME

PRIVATE MOON LANDER

WIFFLE BALLS

AND MORE!



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Billions of microbes live in our midst. One biologist wants to map them—starting in your kitchen.

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RAJ KISHORE PANDEY**

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What's living inside
this sponge?



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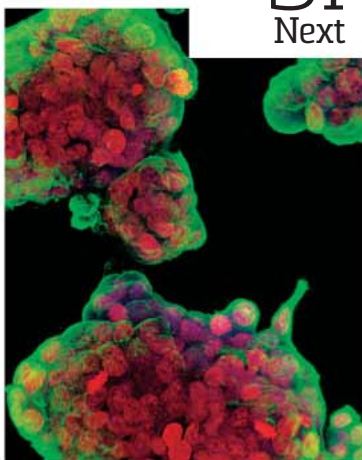
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Editor: Girish Mallya

WORKING IT

How do things work? It is probably the question that has been the bedrock of science since time immemorial; possibly what Socrates wondered when he discovered the earth was round. And it's a question that persists in modern science, leading to some amazing discoveries. This April, Popular Science has undertaken upon itself to bring you fascinating inside stories for some truly inspirational creations. This is the annual How it Works list and covers a gamut of products, vehicles, tools and toys, from what's going on beneath the earth's surface to the first fully electric racing car series.

Speaking of discovering the inner workings, we take a step back in time and revisit the origin of nano-carbons that were discovered through one man's perseverance and passion.

This issue also brings you the inside story of the rise and eventual fall of a Mexican cartel and the role technology played in its ascension.

And if this is not enough mental stimulation, we show you how you can aim really high, and build yourself a life-size Lego creation.

Grab on to this issue. You will thank us forever!



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DAMON TABOR

For his feature "Radio Tecnico" (page 48), Damon Tabor spent four years investigating Jose Luis Del Toro Estrada, the man behind a massive, covert radio network used by the Zetas drug cartel.

Tabor traveled to Texas and Mexico to interview sources, venturing into cartel-controlled regions. What kept him going? "The fact that [Del Toro Estrada] had built something of such a grand scale and few even knew about it. No one had seen anything like this before."



SCOTT ALEXANDER

When Scott Alexander began researching iBeacon (page 23), which tracks our location through a smartphone, he saw a frightening parallel between it and the cookies websites use to monitor consumers. While iBeacon could have helpful applications, such as hyper-immersive games, it could just as easily be exploited by marketers. "It's a consumer technology but wasn't necessarily built with the consumer's best interest in mind," Alexander says.



REBECCA BOYLE

In 2009, Rebecca Boyle wrote her first story for Popular Science about the moon. This issue, Boyle returns to the subject with a story about the Google Lunar XPRIZE, a moon-exploration competition (page 40). "I was most struck by the idea of this being the robot derby on the moon. There's probably going to be a bunch of rovers attached to one or more landers," she says. "Several will hop off and just start driving around."



GRAHAM MURDOCH

For this month's cover, illustrator Graham Murdoch created an exploded view of the new Formula E racecar. Before he even got started, he spent a day researching. It then took an additional 72 hours to put together the image, starting with the shell of the car. "It's all 3-D-modeled," he says. "The idea is straightforward, but it's hard work, pushing and pulling things about until you have something dynamic and informative."



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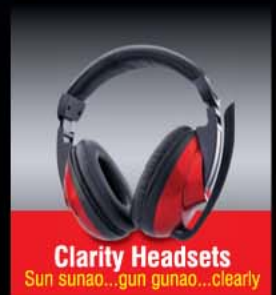


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Peer Review

Enjoyed reading about the DIY projects in the March issue. It's really incredible what people cook up! Even as someone who doesn't really understand science or tech too well can get inspired to try their hand at it! Really interesting stuff. And as usual, I liked reading about the goods and gadgets out in India. It really gives you an idea of what to buy if you're looking for something. Great issue!

Mahesh, Mumbai

I was honestly hooked on to the issue when I saw the cover itself! Who would've thought that there's actually a science involved in sleeping correctly! And the article really lived up to the cover. It went beyond just the regular 'sleep is important' stuff that we all know about. I really think it can be a lot of help to a lot of people, even those who get their 8 hours! Really cool story.

Megha, Delhi

Your March issue was very interesting. I especially liked the main feature on sleep. The article was very informative and really in depth. It really gave a new perspective on the idea and importance of sleep. I also loved the 'Briefs From Around the World' section. As usual it was fun and informative. And the five DIY projects were really cool. And the best article was about the addictive video game. That one i identified with, coz i love games! Gonna find out more about it for sure.

Vikram, Hyderabad

Loved the car and bike review. Can't believe the 800 has been phased out! Here's hoping that the Celerio is a good substitute. And the bike looks amazing. Definitely going to drop into the nearest showroom and give it a once over. By the way, I love the



new look of the mag but any chance you can get the 'Megapixel' section back? Some of the photographs were really amazing!

Rohit, Mumbai

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Inside: The quantified athlete. A light that sets your energy level. Beer-flavored jelly beans and nine other things we love this month. **500-yard headlights.** The psychology of persuasion in ABC's *Mind Games*. iBeacon: good or evil?

Now

EDITED BY *Corinne Iozzio & Amber Williams*



A Telescope That Finds Stars for You



For non-astronomers, stargazing may seem simple: Just plop down a scope, and peer toward the heavens. It's usually not quite that easy. Scopes can be tricky to set up and celestial objects elusive. The Celestron Cosmos 90 GT uses a Wi-Fi connection with a smartphone to do the hard work for you. To align it, users point it at any three bright objects in the sky; the scope uses them to triangulate its precise location. Through an app, users then select the celestial body they want to see from Celestron's 120,000-entry database. Motors in the base position the scope in seconds. **KATIE PEEK**



A full moon, when seen through the high-power eyepiece, fits perfectly into the telescope's sights.



Celestron Cosmos 90 GT Wi-Fi Telescope

Telescope aperture 3.5 inches

Magnification high-power eyepiece, 91x;
low-power eyepiece, 36x

Astronomical database 120,000 objects

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The New Era of Sports Stats

Sports have always been about numbers. We obsessively rank and handicap athletes based on averages and percentages. But while we can tally jump shots or backhands, we've never been able to fully understand why some are successful and others aren't. Now manufacturers are releasing equipment embedded with data-gathering capabilities, allowing a first look into the dynamics of any shot.

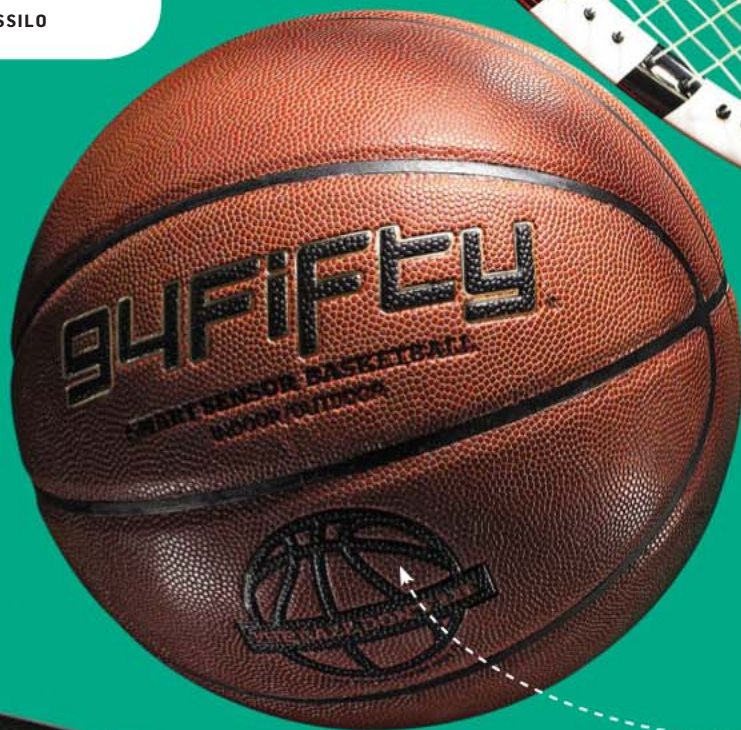
By and large, the gear will appear unchanged. The Babolat

Play tennis racket, for example, has the same weight (300 grams) and balance as the base Pure Drive model—even with a circuit board in the handle. The difference is the mountain of data the equipment collects, much of which can help players improve. For instance, the app for the 94Fifty basketball may offer advice on how to get more arc on your jump shot.

Fans may benefit too. With a fresh set of data to pore over, they'll have something

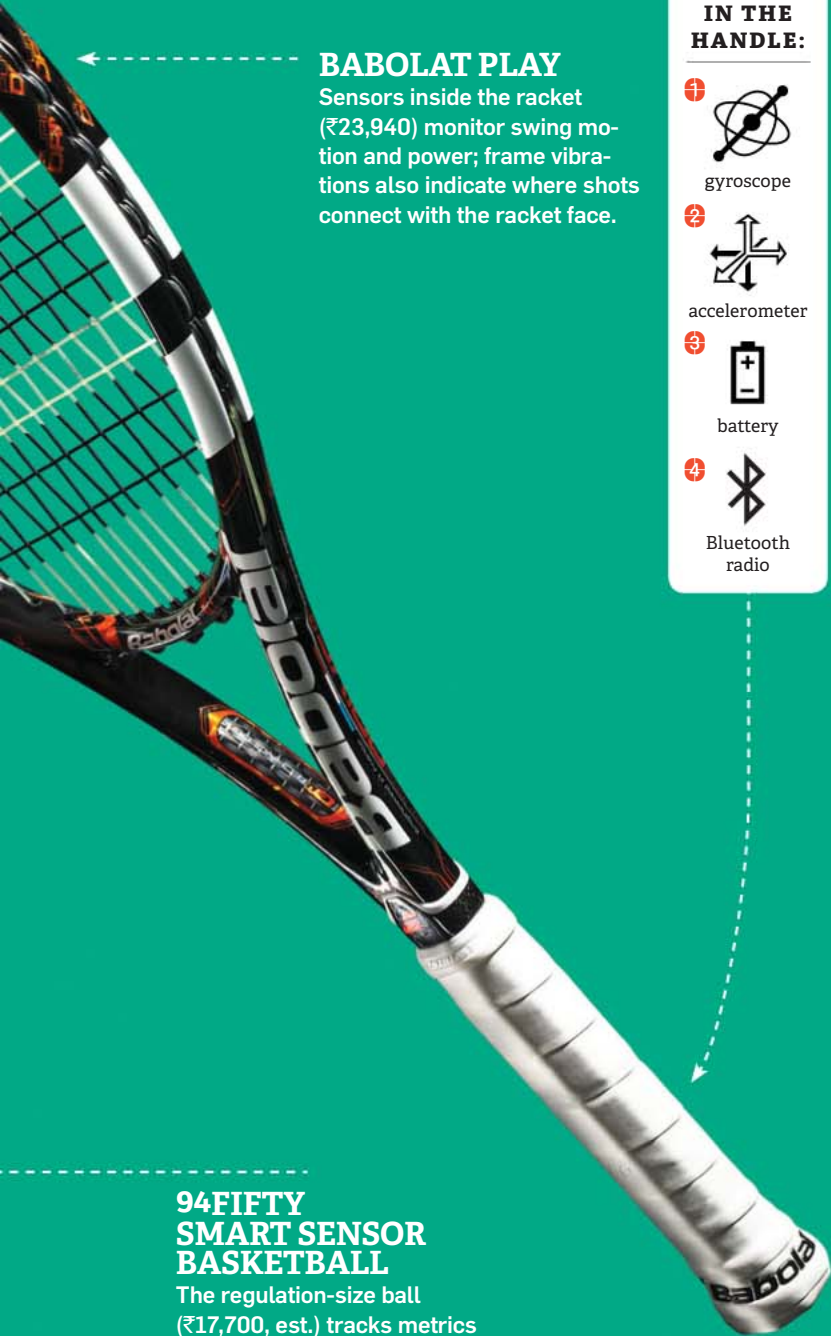
new to obsess about. Perhaps they'll even answer that long-vexing question: Was that incredible shot the result of pure skill or just plain luck?

DAVID CASSILO



KAYAK POWER METER

One Giant Leap, a New Zealand company, developed the Kayak Power Meter (\$999) to record a rower's cadence.



BABOLAT PLAY

Sensors inside the racket (₹23,940) monitor swing motion and power; frame vibrations also indicate where shots connect with the racket face.

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radio

94FIFTY SMART SENSOR BASKETBALL

The regulation-size ball (₹17,700, est.) tracks metrics including dribble control, shot speed, and basket-entry angle.

WHAT IS USB TYPE C?



SIMPLY PUT

It's an upcoming type of USB connector that can be plugged into a port in either direction. Hallelujah.

A LITTLE MORE DETAIL

Expected in mid-2014, the new standard will deliver the same transfer speed (up to 10 gigabits per second) as its predecessor, with a couple of notable improvements: The plug will be smaller—about the size of current **micro USBs**—and reversible. Once the standard is complete, device manufacturers will be free to integrate it, and accessory makers will release the inevitable slew of adapters for current-generation connections.

CORINNE IOZZIO



DAN BRACAGLIA



Netflix's current paid U.S. subscribership, at least three million more than HBO's. The streaming-video service has made it abundantly clear that it aims to steal premium-cable viewers. CEO Reed Hastings recently joked that the HBO CEO's password is "netflixbitch."

NOW



Obsessed

Some things are just . . . better

AMBER WILLIAMS

1 Ryno

The Ryno looks like the love child of a motorcycle and a unicycle. But unlike either, there's little balancing required: A gyroscope and accelerometers help keep a rider upright. Leaning forward accelerates the electric bike to speeds up to 16 kmph. ₹3,18,000

2 Transcendence

In this movie, Dr. Will Caster (Johnny Depp), an AI researcher, wants to create a machine that has both exceptional analytical power and real emotions. After a radical anti-technology group tries to kill him, his colleagues upload his consciousness as a test. And, well, all the power starts to go to his head. April 18

3 A Year With Minecraft

In just three years, *Minecraft* has sold more than 33 million units; an indie video game has never been so popular. In his book, Thomas Arnroth documents the rise of its creators, the world of its fans, and the unexpected influence of a concept based on building blocks. ₹1,080

4 Nendo Cubic Rubber Band

Our favorite design this month is a cubic rubber band. The shape does two things: It makes the band easier to pick up and gives it a firmer grip. We still haven't found the best way to shoot the thing, though. ₹600

5 Jelly Belly Draft Beer

Meet the world's first beer-flavored jelly bean. It has wheat and sweet flavors, like the Hefeweizen it was inspired by—and while it doesn't contain any alcohol, you can eat it with a Red Apple bean for a G-rated apple-cider shandy. ₹1,189/kg

6 Crescent Switchblade

This multi-tool has four interchangeable heads—three blades and a plier—for various activities, such as shingle work and cutting wires. ₹1,500

7 Moog Theremini

Hitting the right note on a theremin is surprisingly difficult. So Moog added pitch control to its latest model. With the control turned up, it's impossible to play a wrong note. Lessen it, and there's room for vibrato. ₹19,140

8 NoWait

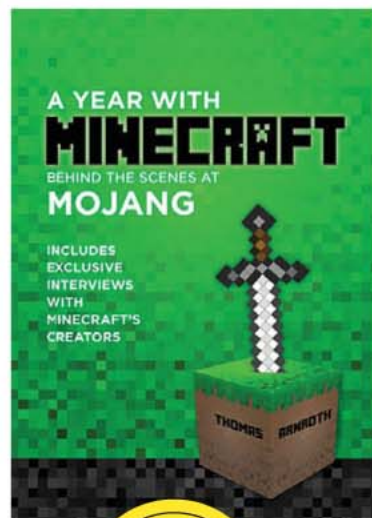
Put your name on a restaurant's wait list from anywhere with this app. Then monitor your place on it in real time. Free

9 Flir One

The Flir One is a thermal imaging device for the iPhone. It detects infrared energy from 0°C to 100°C. Uses include seeing in the dark, locating heat loss, and cheating at hide-and-seek. ₹21,000



**SNEAK
PEAK**

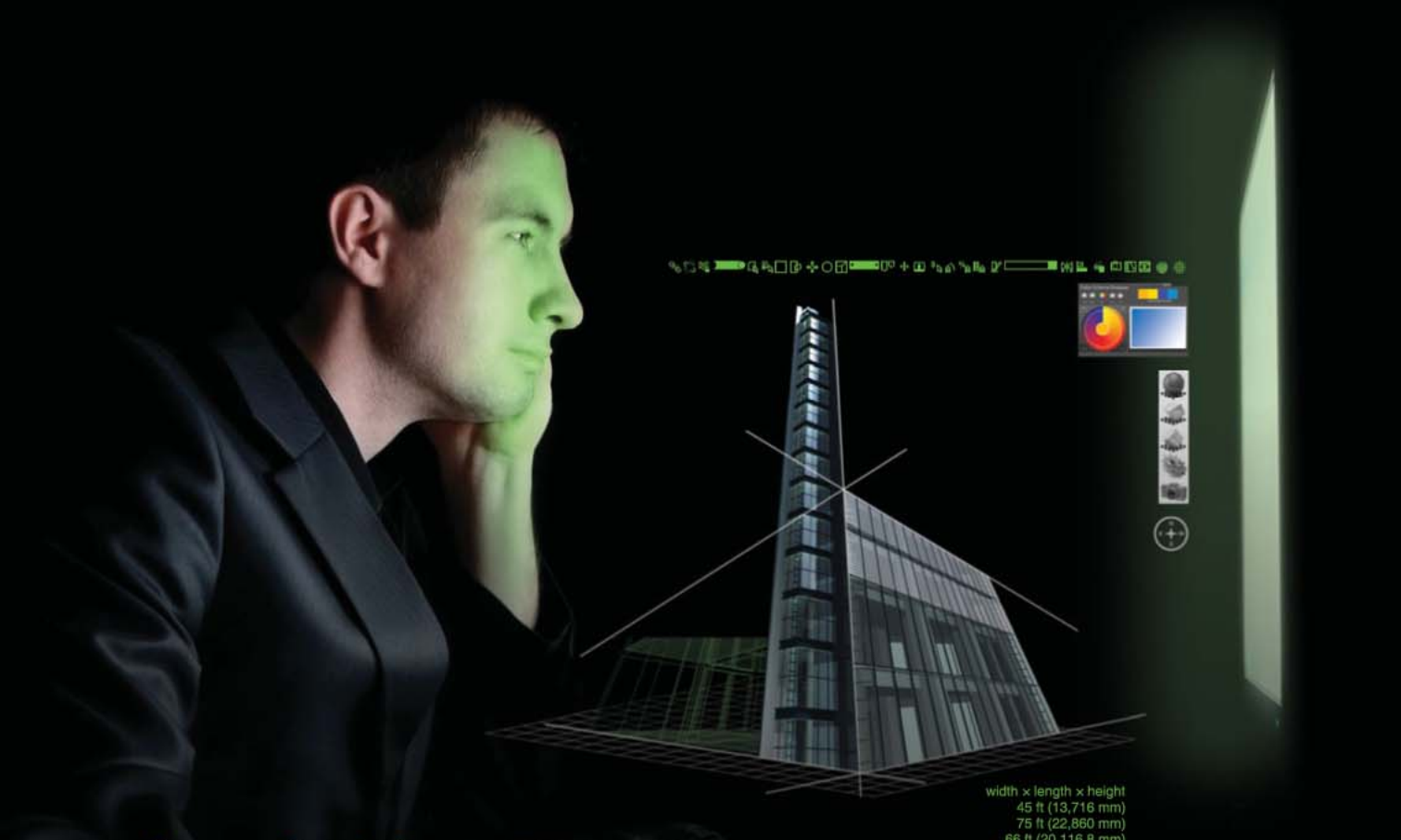


10 KINGS ISLAND BANSHEE

The world's longest inverted roller coaster opens this month in Mason, Ohio. In two minutes and 40 seconds, riders roar through seven inversions, including a "zero-G-roll," and reach speeds of 68 mph. Ready for a road trip? April 18



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The 500-Yard Headlight

2x

Concentrated laser light doubles the range of LEDs, which top out at around 250 meters.

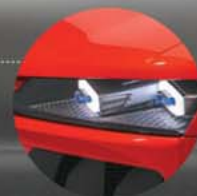
There are headlights that sync to your steering, ones that shift their aim when the road curves, even ones that dim their glare when they sense other cars. But with the new Laserlight system, Audi is returning to the basics: making beams brighter.

Engineers replaced standard high beams with blue laser modules. Laser diodes shine through a phosphor plate, which turns the

glow white. This creates brights that are three times as powerful as LEDs and can illuminate beyond 500 yards. Brighter lights means better visibility and safer driving. (Don't worry, they also dim when another car approaches.) The lights are already on Audi's R18 e-tron Quattro LMP1 racecar, but because of U.S. safety regulations, their stateside appearance may take a few years. **DANIEL DUMAS**



Audi Sport Quattro Laserlight
Range 500 meters
Laser Lens Yellow phosphorus crystal



Car News You Should Care About



Speaker maker
Bose released a chip that can run noise-canceling software on most cars, not just those with Bose sound systems. It generates sounds that cancel out noise from the engine and exhaust.



In January, Mercedes-Benz began retrofitting QR codes on all models from 1990 onward. In a crash, the codes will direct first responders to rescue plans, including the best way to pry the vehicle apart.



Husky Corporation, a Missouri company, will introduce a program to test a line of robotic gas pumps in St. Louis. The pumps use a suction cup to open gas caps and a motorized nozzle to deliver the fuel.

ONE THIRD

The proportion of dealerships enrolled in GM's new online shopping program. The automaker has sold more than 1,800 Chevrolet, Cadillac, Buick, and GMC vehicles through the portal since it launched last November.



In an effort to equip its future self-driving cars with humanlike intuition, Ford has partnered with researchers from MIT and Stanford University. At Stanford, scientists are working to use sensors that could detect moving objects hidden by upcoming obstacles. **JIA YOU**

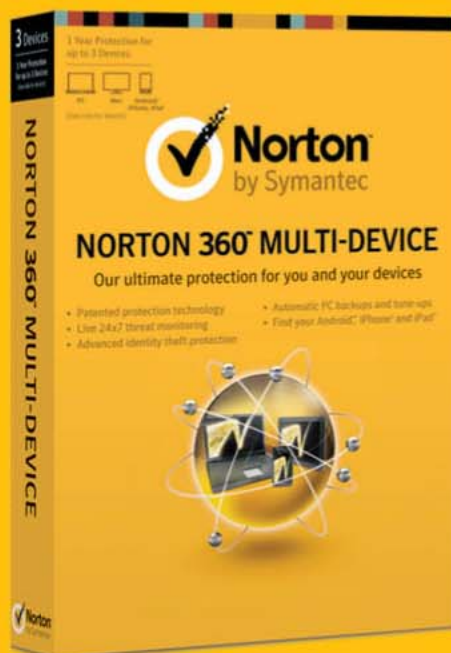


DESIGN OF THE MONTH

Kia may be known for its drab, budget cars, but the GT4 Stinger concept couldn't be further from a standard family sedan. Designers borrowed the turbocharged 2.0-liter, 315-horsepower engine from the company's Optima racer, paired it with rear-wheel drive and a six-speed manual transmission, and sat the entire thing on 20-inch rims. **D.D.**

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Trick Others into Doing Your Bidding

*

INFLUENCE A DECISION BY INTRODUCING A DECOY OPTION

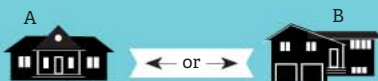
Coined by Duke professor Joel Huber, asymmetrical dominance...

(a.k.a. the decoy effect)

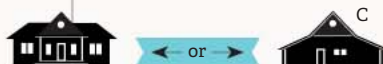


... is a technique Killen borrowed from real-estate marketing.

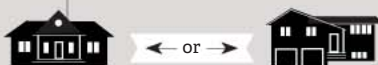
Say you're torn between two very nice but different homes.



Hoping you'll choose House A, your Realtor shows you a similar yet inferior version of it, House C.



The mini contest gives House A extra luster, helping it outshine House B.



And sure enough, people tend to opt for House A.



We like to think of ourselves as rational beings, but there are many ways we can be subconsciously influenced. At least, that's the premise of ABC's new series *Mind Games*. Christian Slater and Steve Zahn star as consultants who use psychological techniques to manipulate their clients' bosses, co-workers, and family members. Writer and executive producer Kyle Killen pored over scientific research in marketing, psychology, and consumer behavior and found a number of real-world methods the characters can use to bend minds. **ADAM HADHAZY**

A former university psychology professor (Zahn) and an admitted con man (Slater) team up. What could possibly go wrong?



REVIVE A PRIOR OPINION BY REACTIVATING A MEMORY

Memories tend to bundle sights, sounds, smells, feelings, and associations into one contextual package.

That's why the aroma of freshly baked cookies can conjure images from childhood.



Recently scientists at Northwestern University found that some sensory cues can activate memories when subjects are asleep.

By exposing subjects to olfactory and auditory cues while they slumber...

... the scientists could secretly trigger long-forgotten memories that would color the subjects' opinions after they wake.

ALTER A PERSONALITY BY BOOSTING ADRENALINE

An adrenaline rush tends to sear extreme situations into our memories.

Upon reflection, people usually look back on those situations as "character-defining."

(brawls or car crashes)

In theory, then, manufacturing an adrenaline spike could allow people to implant a self-perception of their choice.

Want your brother to behave charitably, for instance?

Get his adrenaline pumping in a heated encounter with an aggressive stranger.

Add another person upset by the stranger, and your brother will help.

* Ha! This arrow tricked you into reading the wrong thing first, didn't it?

Tired? Wired? This Bulb Can Help.



THE PROMISE

It might shine like any other bulb, but the Rhythm Downlight LED from Lighting Science (price not set; available summer) can make users feel energized or sleepy on cue. NASA plans to deploy similar technology on the International Space Station to help astronauts regulate their sleep. (At 28,158 kmph, they see 16 sunrises and sunsets every 24 hours.) **JIA YOU**

3.5

The approximate loss in hours of Americans' nightly sleep since the invention of the lightbulb.



THE RESEARCH

Scientists at Thomas Jefferson University and the Uniformed Services University of the Health Sciences recorded how volunteers responded to different wavelengths of light from 440 nanometers (nm) to 600 nm. The spectrum they used ranges in color from indigo to orange. Subjects underwent exposure in 90-minute intervals, while researchers recorded melatonin levels in each participant's blood.

THE RESULTS

The team found that blue light measuring 446 nm to 477 nm suppressed production of melatonin, which promotes drowsiness, more than other wavelengths did. Engineers at Lighting Science used that data to program the Rhythm Downlight with multiple settings, including energizing (more blue) and relaxing (no blue). Users program their schedule through an app, allowing them to stave off mid-afternoon crashes before they start.



Scott Alexander is a New York City-based writer who covers technology, videogames, and photography.

Watch out for iBeacon—because it's watching you

COLUMN BY SCOTT ALEXANDER



PLING! YOUR PHONE LIGHTS UP: "MAKING TUNA SALAD? DON'T FORGET THE MAYO! 20 PERCENT OFF MEGAMART BRAND."

and share data. Manufacturers of health and fitness trackers have already put BLE to good use, creating devices that can gather data for days without a recharge. iBeacon makes it even easier to implement such exchanges, but not every company has our best interests as much at heart.

iBeacon will allow companies to mine and use data about you in real time. With multiple iBeacons in place, stores can pinpoint your precise location, allowing them to monitor your browsing habits and promote products you're likely to buy. We're used to Amazon doing this, but soon your local MegaMart will be able to also. Say, for instance, you pick up tuna fish and then some celery. *Pling!* Your phone lights up: "Making tuna salad? Don't forget the mayo! 20 percent off MegaMart brand." While we're curious about this new era of extreme couponing, it's easy to see how stores might misuse it.

That said, there are some helpful uses for location-specific information. Major League Baseball parks, including Citi Field in New York, will use iBeacons to guide you to your seats. (Citi will also use the system to sell you discounted hot dogs.) Radius Networks, a Washington, D.C., company, has released an iBeacon development kit, which individuals can use to build their own apps. Museums are talking about using the technology to push information about artwork to visitors as they move through galleries. And there's potential for fun: Companies have used iBeacon to set up large digital scavenger hunts, and developers are cooking up games that could allow for spontaneous pickup matches that bridge the real and virtual worlds.

The trouble is, iBeacon is an all-or-nothing scenario. The only surefire way to turn it off is to turn Bluetooth off altogether—also shutting down the connection to your headset or fitness tracker or smartwatch. But that's not realistic; we're attached to Bluetooth. Which means it's up to individual developers and companies to make the right choices and treat us, our privacy, and our attention with a little respect. 

Last June, Craig Federighi, Apple's senior vice president of software, sneaked something big into his Worldwide Developers Conference keynote. On a slide listing features that would debut in iOS 7, an unfamiliar word appeared: *iBeacons*. An iBeacon is a small module that makes a spontaneous Bluetooth connection with a nearby **smartphone** to deliver packets of information. In December, stores, arenas, and other venues began to test the hardware, pushing coupons and other location-based information to customers. Like any technology, iBeacon is not inherently good or bad; it's how we use it that will make the difference.

To understand iBeacon, it's important to understand the underlying technology, Bluetooth Low Energy (BLE). Unlike previous Bluetooth devices, BLE ones don't need to maintain a constant (and battery-draining) connection in order to share data. Instead they ping packets of information from their stationary locations. Only when another device comes into range will the two make a connection

200

The estimated number, in millions, of iBeacon-ready iOS devices already in the wild. Sixty percent of Android devices are also compliant.





1

These new running shoes are the first of their kind to have 16 individually tuned forward-angled blades instead of a traditional midsole that enhances the energy in your feet. The shoe fits on like a glove and has ample breathing space to take care of internal heat. Even though the shoes may seem a tad heavy as compared to the current light-weight breed of running shoes, the innovation makes it worth buying. Shock absorption is another reason to consider these shoes.

Adidas Springblade : ₹ 14,999; available online and at retail outlets

2

MapMyIndia, which makes GPS gadgets and mobile apps, has created the Smart Mirror which consists of a rearview mirror, navigator, and reverse camera screen for your car, all combined into one gadget. The 5-inch GPS screen doubles up as a rearview camera. This is an effective way of always keeping your eyes on the front. The device also has 2 GB storage and an extra SD card slot for a 4 GB card to store music, if you like.

Smart Mirror: 15,990; available available online

3

JBL's new headphones for the budget-minded customer adds some serious punch to the bass notes in your music. The headphones have dual rotating ear cups, has a 40-mm speaker diameter, and 117 dB sensitivity. This product has an integrated microphone with adjustable volume. The headband is also adjustable and the headphones are available in red, blue, black, and white.

JBL Bassline Headphones: ₹6,990; available online and at retail outlets



4

These Bluetooth eyeglasses give you the comfort of hands-free without the hassle of a Bluetooth headset. Kagawa has enabled users to put the piece on one of the stalks so that there is no extra equipment to be added. These glasses are available in rectangular, aviator, and other styles. Some of the models offer UV protection for your eyes. They come with two device chargers, a USB, and a plugpoint charger.

Kagawa Bluetooth Eyeglasses: ₹ 4,990; available online and at retail outlets

5

Learning was never this interesting. This tablet powered by Android 4.2 is made for 2 to 10 year olds. It has a 7-inch screen tablet and a 1.6 GHz dual-core processor with 1 GB RAM, a 3200mAh battery, and internal memory of 8 GB, which can be expanded to 32 GB with a microSD card. The games on this tablet are meant to teach reading, music etc in a fun way. It also has exploration- and adventure-based games. Parents can access about 50,000 educational apps on the Google Play Store. It also comes with a recommendation engine called Kids Radar, which suggests the most suitable apps for children.

Metis Learning Eddy Tablet: ₹ 9,999; available online and at retail outlets

6

Wiry has a 1.3 GHz dual-core processor, 1 GB of RAM, 4 GB of internal memory, and an 8 GB microSD card, a 4-inch AMOLED display with 360x640 pixel resolution, a 5 MP rear camera, a 2 MP front camera, and is powered by Android 4.2.2. It also offers One Glass Screen (OGS) and In-Plane Switching (IPS). In spite of having all the works, the phone is as slim as 5.8 mm.

WhamWiry W1: ₹ 9,900; available online and at retail outlets

Story by **Jim Gorde**
Photography: **Sanjay Raikar**

Car Review / Right on Qrio

A Celestial Ride

The Audi Q5 receives a more potent diesel motor and we take its top-end avatar to the land of sun and sand to see how much has changed.



The Audi Q5 has become quite the popular SUV, what with its 2.0-liter diesel motor delivering miles and smiles to buyers, while keeping them and everyone they care about in a safe and comfortable environment. However, the 2.0 TDI isn't the only one there; for those who want more of everything, Audi has had the solution since the beginning of the Q5's existence. The updated car with the more powerful V6 has even greater numbers and more thrills up its sleeve.

The new Q5 3.0 TDI packs a powerful 3.0-liter V6 diesel motor and is available only with the S-line trim package. While the power is up by a single-digit figure, the torque gain is massive.

The Q5 has always been an extremely refined, smooth and dependable car, and when traveling, it becomes more than that; it becomes a companion. Spending long hours at the wheel over hundreds of kilometers at a stretch can lead to all sorts of discomfort for the driver and

other occupants as well, and having the right car can make or break the whole experience of the journey. That's where the Q5 ticked all the right boxes.

The seating position is quite high, but the cabin feels familiar and luxury-sedan-like. The roominess of the cabin and the climate control are things all will appreciate. The big V6 turbo-diesel makes so much torque so low down the rev range that the whole process of getting a move on seems effortless from the moment you begin. The huge 75-liter fuel tank meant we wouldn't have to stop anywhere en route. Standstill to 100 kmph is just over seven seconds away. At no point did the car feel like it was running out of breath, because we knew we really weren't anywhere near the limits of its performance.

Under the bonnet, the 3.0-liter V6 TDI diesel motor makes 245 PS between 4,000 and 4,500 RPM and a hefty 580 Nm of torque from just 1,400 RPM, which stays up until 3,250 revs, and

it's paired to the seven-speed S-Tronic transmission and the signature quattro all-wheel drive. The car's smart, onboard electronics optimize power delivery to suit every road surface and give the driver a feeling of complete control while ever so gently reassuring one of the fact that the car is indeed capable of more. The drive is split 40-60 front and rear, but can be varied to suit traction levels within milliseconds of any detected slip due to a change in road surface.

The brakes are equally commendable and make short work of stopping this near two-tonne crossover. Braking from 80 kmph to a dead halt takes less than 2.5 seconds and 25 meters. The steering feel, too, is sublime for a car of its segment, giving just the right feedback and feeling well-weighted indeed. The Q5 can pleasantly surprise you with the way it goes about doing what it does. It may sit higher off the ground and eat up luggage, but it behaves like a sedan. The high ground clearance lets you take on questionable terrain while on sweeping corners; you can push it as you would any well-handling sedan. It adheres to the definition of "crossover" in its ideals and is simply the benchmark. It also cuts short the travel time with its speed, and keeping things comfortable with its spot-on ergonomics means you don't really feel like you've covered all that distance.

Another benefit was efficiency. A big V6 with four-wheel drive was never going to win a fuel-efficiency contest, but the big Q5 doesn't disappoint. We worked out a figure of 12 kmpl on the highway, while in the city, it drops to eight; not bad considering the comfort level it has to offer.

It's not as bulky as its big brother, the Q7, and it offers an appreciable balance of comfort, power, and economy for us to consider it a winning all-round package. 

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Demonic Resurrection

Flashes of green and a menacing stare are the first things you notice on Kawasaki's latest Z1000.



The Z1000 is a unique motorcycle.

It's about unadulterated design, immense power, and massive appeal, and this time round, it brings impeccable quality and incredible levels of fit-and-finish. The design is essentially street-bike with a mean makeover. The riding position is relaxed and ergonomics would make for comfortable journeys, long and short. The saddle is the right amount of firm and gives good support on the open road or even in traffic. It's not a high-performance-oriented bike, but it can deliver! The 221-kg kerb weight makes it lighter and more manageable than even its smaller sibling, the Z800!

On the equipment front, you get grippy Dunlop tyres and petal disc brakes with Kawasaki-etched monobloc callipers and ABS. The front suspension is adjustable for pre-load at the top ends of the fork. Turn the key and the instrument cluster lights up with a unique light sequence before settling down and giving you a view of your fuel level, trip and odo. The seat looks as if it's made from snake-skin and then dyed black, when, in reality, it's black leather and a barrage of those lightning-

shaped "Z" logos. Peek lower and you see a set of twin-exhausts; and these are no copper-colored parallel pipes. The stealthy, chunky exhaust enders look like they were forged by a coalition of Dwarven smiths and sorcerers—like fragmented metal armor polished to a smooth finish, but left without sheen.

Putting the muscle in muscle-bike is the all-new 1,043-cc inline-four motor features what Kawasaki calls DFI-technology that resembles direct-injection and sharpens power delivery. Peak power of 142 PS comes in at 10,000 RPM with a more than reasonable 111 Nm of maximum torque coming in at a rather low 7,300 RPM. A chunk of it comes in early, though, and that helps rideability no end: less left-leg shuffling from the well-spaced six-speed gearbox.

Thumb the starter and the motor comes to life with a growl. The exhaust note is all bass and there's no real scream till much higher up the revs. The rev counter atop begins at the 4,000 mark, with the first 3,000 revs registering to the left of the digital display below—a very unique bit. As we headed to the twisting

roads to see how it handles the bends, I found the Z1000 to be very nimble; even flickable. It does feel like a big bike, but it also lets you feel like you're in control. The ride is good and the bars-to-seat-to-peg locations are just right for a comfortable position. Going into corners doesn't really take much getting used to either. It does take commitment, but the big Z lets you take them in your stride.

On the straight, the Z rockets forward when pushed and the burly bass turns into higher-pitched howl which gets your pulse up quicker than the lights on the top rev-counter can fill up. Hitting 160 kmph is no biggie and the Z remains steadfast. Kawasaki claims a top speed of close to 250 kmph, but where I was, there was no way I could get anywhere near that figure.

Another important characteristic is the 17-liter fuel tank. With a conservative efficiency of about 12 kmpl, we made a mental note for a range of just over 200 kilometers. Another number to consider is the price. At Rs 12.5 lakh (ex-show-room), the Z1000 is five lakh rupees more expensive than the smaller Z800. 🏍️



Inside: How climate change is affecting your garden. A pacemaker powered by heartbeats. **The man who works with wild animals and robots.**

Go to page 42
to see how 3-D
glasses work.

Next

EDITED BY *Susannah Locke & Amber Williams*



40x

Magnification

SEEING CELLS AS THEY'RE MEANT TO BE SEEN: IN 3-D

Cells live in a three-dimensional world, but until recently, scientists using fluorescence microscopes could see them well in only two dimensions. With advances in confocal microscopes, which use pinhole apertures to focus light on several planes, scientists can now view samples with depth, like these human prostate-cancer clusters. **LINDSEY KRATOCHWILL**

Source: Louisa Windus, at Griffith University in Queensland, Australia, studies how cancer cells grow and spread.

Average change in spring temperatures in Concord, Mass., since Thoreau lived there in the mid-1800s.

The New Spring

How climate change has shifted spring's emergence, in five charts

BY **Katie Peek**

PHOTOGRAPH BY
Jonathon Kambouris



As the planet warms, the temperatures that trigger spring arrive earlier. But not everything's adjusting on the same schedule. Flowers open before their insect pollinators come out, and birds return from migration too late to find their usual bug meals. Detailed study of ecological mismatch requires equally meticulous observations

of historical timing—and a Boston University lab has found a trove in the journals Henry David Thoreau kept in Massachusetts in the mid-1800s. "They're probably the oldest detailed records of flower and bird-migration times in the United States," says Richard Primack, a conservation biologist who runs the BU lab. The diaries, together with more recent data, reveal an ecological system in flux.



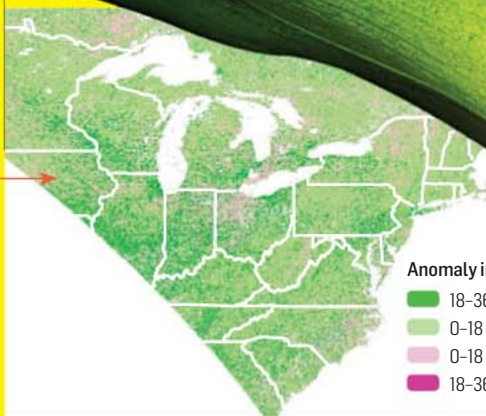
Want to know more?

Walden Warming: Climate Change Comes to Thoreau's Woods, by Richard Primack, comes out this month.

1

Leaves appear earlier

In 2012, plants leafed out a full month early in some parts of the Northeast, as measured by satellite images that document levels of foliage. Scientists attribute the premature greening to abnormally warm weather.



Anomaly in leaf arrival

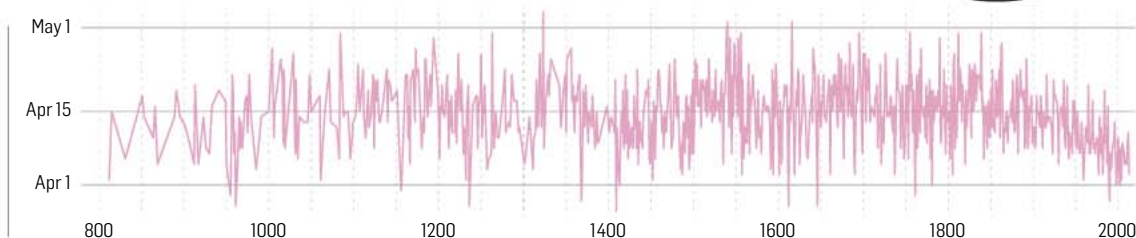
- 18-36 days early
- 0-18 days early
- 0-18 days late
- 18-36 days late



2

Cherry trees bloom earlier too

More than 1,200 years of cherry-blossom records for Kyoto, Japan, show a trend toward earlier blooms in the past 100 years.

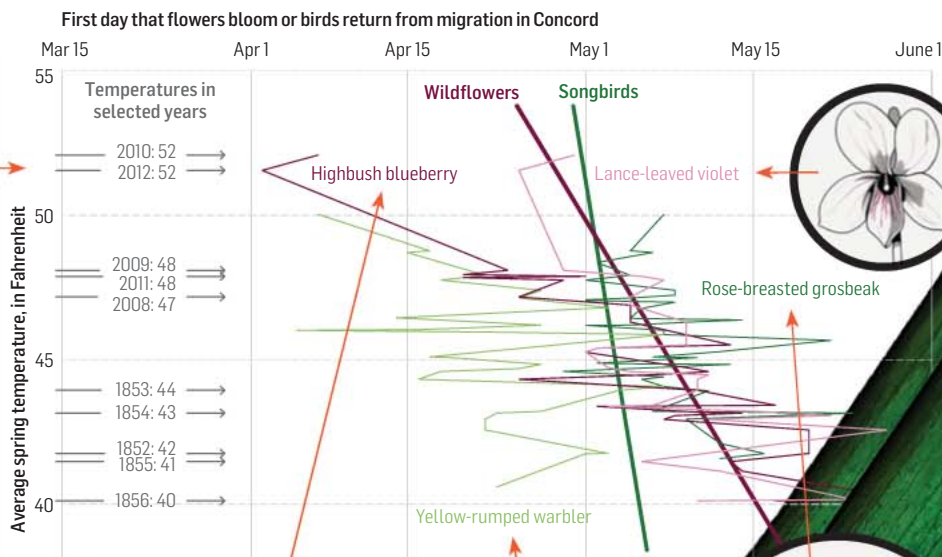


3

Flowers precede birds

Nearby Boston delivers extra heat to Concord, making the town a case study for global warming in the Northeast. Wildflowers [pink] seem to respond to the new spring temperatures more than migrating songbirds do [green].

Nerd box: The trends [thick lines] average 32 flower and 22 bird species that Thoreau tracked. Four species [thin lines] are included as examples, and average spring temperatures for the first and last years in the data set are listed [near right].



4

Birds lag behind bugs

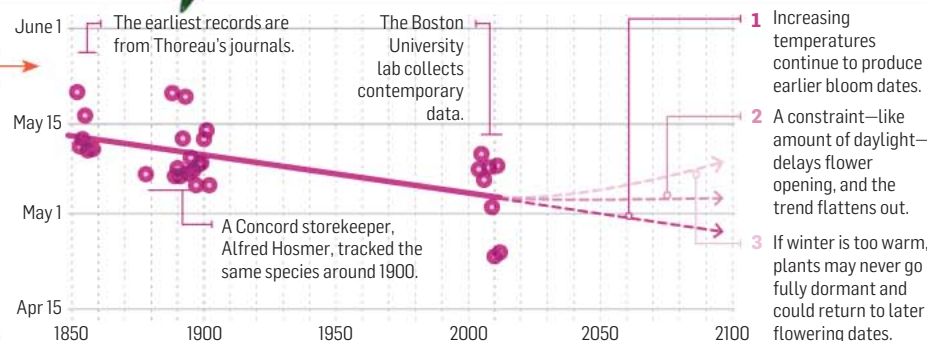
In Concord, insects, too, have responded to warming at a different rate. The BU lab has measured how many days each spring indicator shifts per Fahrenheit degree of warming [boxes]—though individual species vary [bars].



5

The future is uncertain

The wildflowers in Concord bloomed three weeks earlier in 2012 than they did in the 1850s, when Thoreau observed them. Ecologists see three possible futures for how spring may continue to evolve.



CERAMICS COULD PREVENT NUCLEAR DISASTER

Pottery just got really high tech



For more than 50 years, engineers have built the rods that hold nuclear fuel the same way, out of zirconium-based metal alloys. They maintain structural integrity at high temperatures and allow uranium neutrons to escape in order to produce nuclear reactions. But, as Fukushima demonstrated, they have a very serious drawback: At about 1,093°C, the stuff quickly reacts with steam, releasing heat and hydrogen gas that can easily ignite—and then explode. **JESSE EMSPAK**

1

Silicon carbide (SiC) ceramic rods can do everything that zirconium-based ones do.

2

But they are far less reactive with hot water.

3

And they're still strong at 1,593°C and higher.

4

Several companies have been working on SiC rods, including Maryland-based Ceramic Tubular Products, which tested them under accident conditions last year.



HOW TO... AVOID TRAFFIC JAMS

Most gridlock strikes when the quick braking of one driver ripples rapidly down a string of cars. "There is no accident, there is no bottleneck—it is a phantom blockage," says Berthold K. P. Horn, a computer scientist at MIT. Horn recently developed an algorithm that shows traffic can flow more smoothly when people follow certain rules. Here's what you can do to help:

1. Pay attention to the car behind you, and maintain an equal distance between it and the car ahead. With a buffer, if the driver in front briefly brakes, you won't pass the hiccup along.

2. Drive at the same speed as the cars around you. Accelerating to catch up to the vehicle ahead will result in braking or switching lanes, which may force another driver to slow suddenly.

3. Buy a car with an adaptive cruise-control system to automatically sync your speed with surrounding traffic. Or, save up for when a self-driving car hits the market. KATE BAGGALEY

1 GENE

That's all that separates the queen bee's genome from her workers', according to a study published in January. The gene, *Ultrabithorax*, gives worker honeybees special wing and leg features, such as bristles, that help them carry pollen.

WHEN RATTLE- SNAKES AND ROBOTS COLLIDE

Daniel Goldman spends his days working with venomous rattlesnakes, baby sea turtles, and a dozen other types of animals. But he isn't a zookeeper, or even a biologist. He's a physicist, studying locomotion at Georgia Tech. In order to test his hypotheses, he builds robots that mimic the ways animals move. Jealous yet?

EDITED AND CONDENSED BY
FLORA LICHTMAN



Popular Science: *Why do you have so many sandboxes?*

Daniel Goldman: No one has ever studied the complexities of a sidewinder rattlesnake's movement on sand, its natural substrate. In principle, you can understand how a hummingbird stays aloft or how a shark swims by solving fluid-dynamics equations. We don't yet have fundamental equations for complex terrain—sand, leaf litter, tree bark. To figure that out, we built giant sandboxes that are equipped with high-speed cameras and can tilt to mimic dunes.

PS: *Which animals are the hardest ones to work with?*

DG: The rattlesnakes were a lucky break. You put them in a sandbox, and they just start sidewinding—the sideways slithering they do to cross sand. But most animals don't do what you want. Ghost crabs, for example, are ridiculously fast. In the laboratory, you can get about 10 good trials out of them: They'll run away from you down a track,

where high-speed cameras record them. After that, they seem to decide they are no longer afraid and start trying to pinch you.

PS: *Why do you build robots too?*

DG: We want to figure out how animals move, but they're too complicated to understand all at once. Robots let us systematically vary parameters, like the number of motors or the slickness of the skin, and see how movement changes. We can compare these observations to computer models and animals. I call it robophysics.

PS: *What's your favorite bot?*

DG: They're like children; how can

I pick? I'll say our sand-swimming robot, which is made of several servomotors packed in a sleeve and wrapped in a Lycra swimsuit.

PS: *How will these insights be used outside the lab?*

DG: The locomotion lessons we learn can be fed back into more sophisticated robots. In the future, I think we'll see robots with Watson-like smarts and squirrel-like mobility.

Goldman runs the CRAB (Complex **Rheology** and Biomechanics) Lab. He's worked with zebra-tailed lizards, wind scorpions, and fire ants, among others.

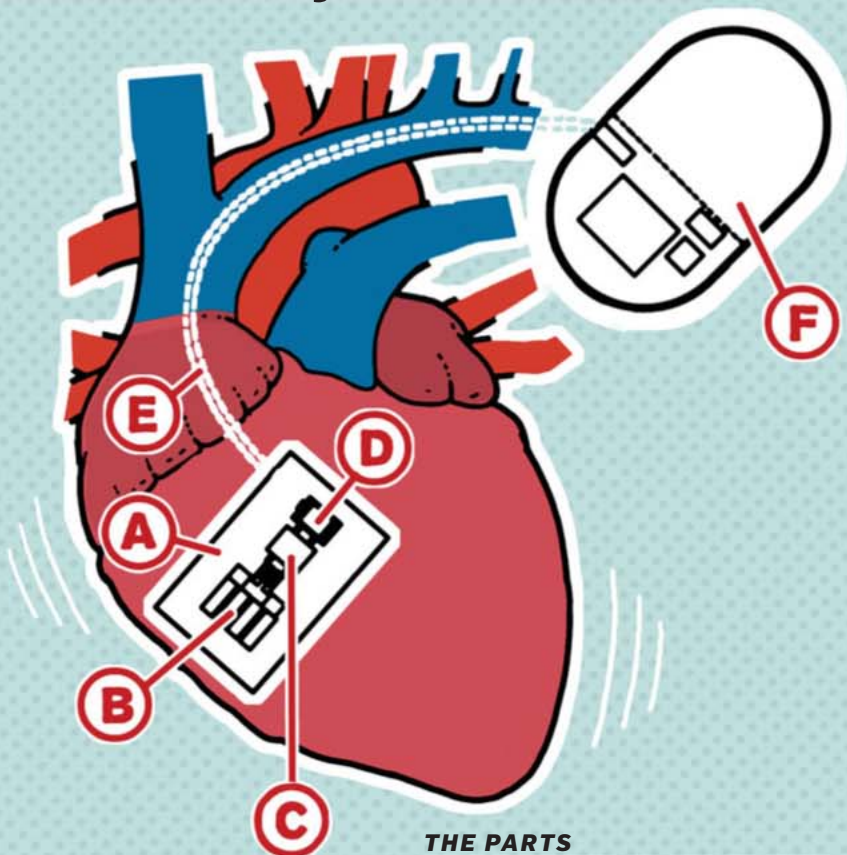
COOL
JOB
ALERT!



Rhe·ol·o·gy / rē-'ä-lə-jē /

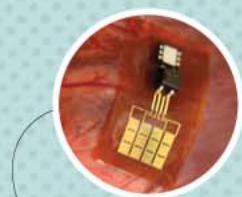
n. the science of the deformation and flow of matter

A Pacemaker Powered by Heartbeats



A pacemaker's battery needs to be swapped out about every five to eight years, requiring surgery. Engineers are now working on a device that converts the mechanical energy of a beating heart into electrical energy and could last indefinitely. A prototype tested in farm animals has generated a microwatt of power, enough to keep a pacemaker going.

FLORA LICHTMAN



The actual prototype is roughly the size of a postage stamp.

THE PARTS

A	B	C	D	E	F
Flexible polymer holds system in place.	Piezoelectric ribbons harvest energy.	Rectifier switches current.	Microbattery stores energy.	Leads connect battery to pacemaker.	Pacemaker controls heart rhythm.

Source: John A. Rogers, professor of materials science and engineering, University of Illinois at Urbana-Champaign

\$\$\$

YOU COULD BE A PROUD OWNER OF MOON DUST



On April 8, Bonhams will auction more than 300 pieces of space memorabilia. We have our eyes on these items:

APOLLO 11 CHECKLIST

Buzz Aldrin used the list—complete with handwritten notes—in preparation for his flight home from the moon.

Est. price:
₹21,00,000–27,00,000

APOLLO 12 MODULE STRAP

Still covered in moon dust, this strap held equipment in place on *Intrepid*, the second manned lunar lander. ₹15,00,000–21,00,000

SCALE MODEL OF LUNAR ROVER

An aerospace company built this 1:7 model of *Lunokhod 2*, a Russian rover that roamed the moon in 1973. ₹6,00,000–9,00,000



SPACESUIT FROM THE '60s

The pressure suit dates to Project Mercury, the first U.S. human spaceflight program. ₹4,80,000–7,20,000

JIA YOU



Virginia Hughes is a science journalist based in Brooklyn, N.Y. She writes the "Only Human" blog at National Geographic.

Stop looking for "hardwired" differences in male and female brains

COLUMN BY VIRGINIA HUGHES



TODAY'S NEUROSCIENTISTS ARE USING NEW TECHNOLOGIES TO UNWITTINGLY PERPETUATE STEREOTYPES.



"brain of intelligence," is larger in men than in women. (Scientists of this era made comparable proclamations about race, claiming, for instance, that the frontal lobe is smaller in "Negros" than in Caucasians.) Today's neuroscientists are doing something similar: using new technologies to unwittingly perpetuate stereotypes that are just as unfounded and just as damaging.

In the past decade, several thousand papers have been published on sex differences in the human brain. Many physical differences are genuine, but often-times not meaningful. Take for example, an easily measurable characteristic: size. One study recorded men's brain volumes at 1,053 to 1,499 cubic centimeters and women's at 975 to 1,398. The overlap means you couldn't tell the sex of a random brain from its size.

In addition, many supposed psychological differences between the sexes are as illusory as the physical ones. In 2005, Janet Hyde, a researcher at the University of Wisconsin-Madison, analyzed data from studies of apparent sex differences in traits such as aggression, social ability, math, and moral reasoning. Nearly four fifths of the traits showed only a minor or negligible difference between men and women.

In the rare cases where actual psychological differences exist, they cannot be attributed to innate neurology alone. Everything in the brain is a combination of nature and nurture. Culture comes into play, which affects behavior, which then affects the brain. From birth (and even in the womb), a baby is labeled as a girl or boy and treated a certain way as a result. For example, a 2005 study of 386 birth announcements in Canadian newspapers showed that parents tend to say they're "proud" when it's a boy and "happy" when it's a girl. Anne Fausto-Sterling, a biologist at Brown University, has shown that mothers talk to infant girls more than infant boys. This could partly explain why girls tend to have better language skills later on. "Some differences end up fairly entrenched in adult human beings," Fausto-Sterling says. "But that doesn't mean that you were born that way or that you were born destined to be that way." 

In December, a highly publicized study declared that distinctive wiring in the brain explains different skill sets in men and women. After scanning hundreds of participants' brains, the researchers reported that men have stronger connections within a given hemisphere, whereas women have stronger connections between the two. This makes sense, they speculated, because same-side connections are responsible for carrying out focused tasks, such as map reading, at which men excel, whereas cross-brain connections underlie the multitasking and social graces that are most often associated with women. Finally, evidence that men are from Mars and women are from Venus! The trouble is, the study is riddled with faulty assumptions and methodological flaws. Worse still, problems like these taint just about every study that claims to show a "hardwired" explanation for why men and women behave differently.

In 1854, German anatomist Emil Huschke reported that the brain's frontal lobe, which he called the

7.71
KG

The weight of a sperm whale's brain, the largest in the animal kingdom.

Source: U.S. National Marine Fisheries Service

THE ANNUAL HOW IT WORKS



THE WORLD'S MOST AWESOME VEHICLES, TOOLS,
AND TOYS, DISSECTED AND DEMYSTIFIED

FORMULA E RACECAR

This year, the first fully electric racing series will debut in cities around the globe. Called Formula E, the new Fédération Internationale de l'Automobile (FIA) championship is the zero-emissions complement to the Formula One (F1) international racing series. Formula E will be open to any vehicle that meets FIA technical specifications, an effort to motivate manufacturers to push the bounds of electric-vehicle technology. But for the inaugural season, all 10 teams (each with two drivers) will race just one model: the Spark-Renault SRT_01E. With oversight from Renault, the French company Spark Racing Technology will build 42 of them, incorporating parts from F1 heavyweights

Dallara (chassis), Williams (batteries), and McLaren (powertrain and electronics). When the first race starts, in Beijing in September, the SRT_01E will show bystanders just what electric vehicles can do.

A

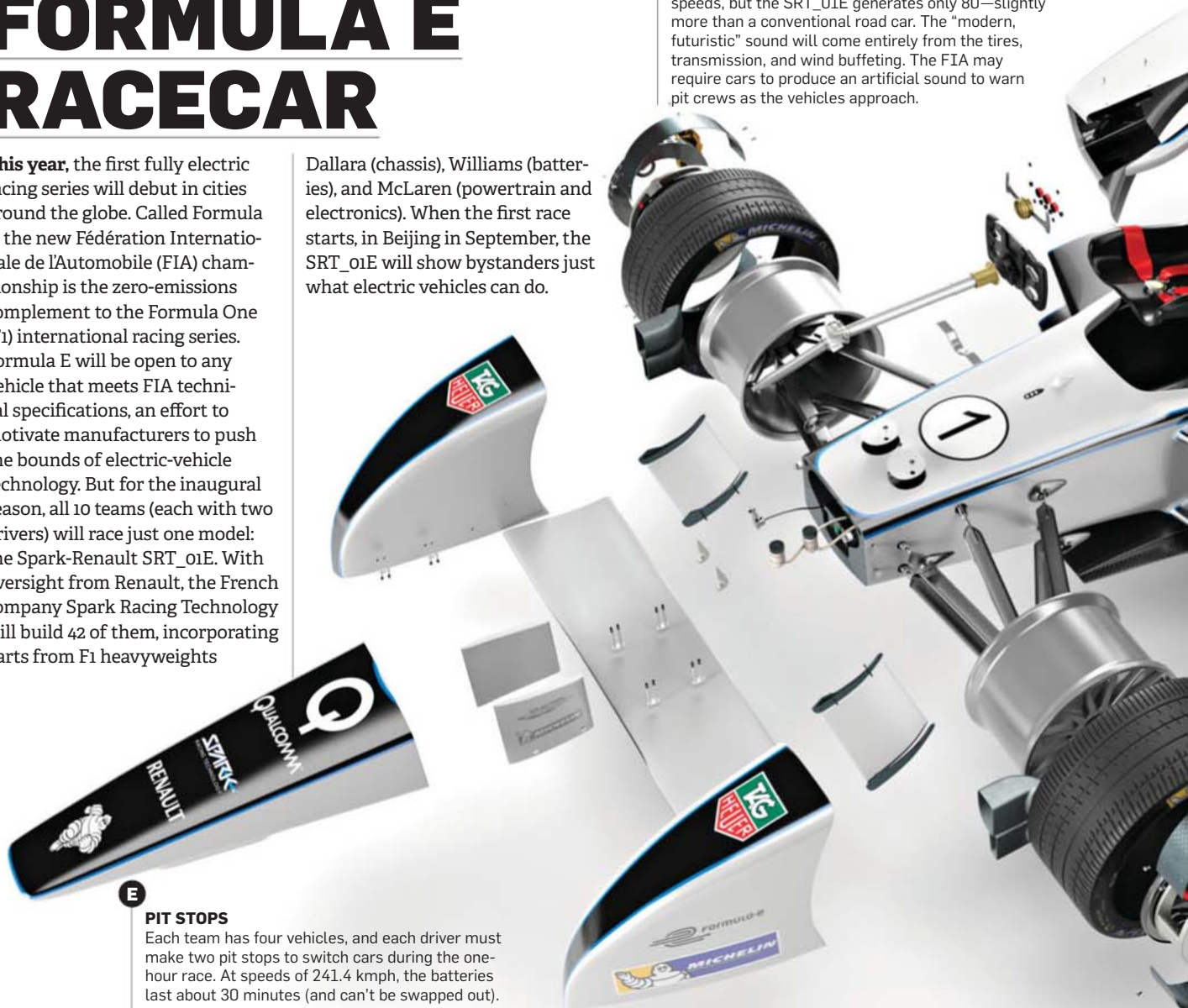
SOUND

F1 racecars typically produce 130 decibels at high speeds, but the SRT_01E generates only 80—slightly more than a conventional road car. The “modern, futuristic” sound will come entirely from the tires, transmission, and wind buffeting. The FIA may require cars to produce an artificial sound to warn pit crews as the vehicles approach.

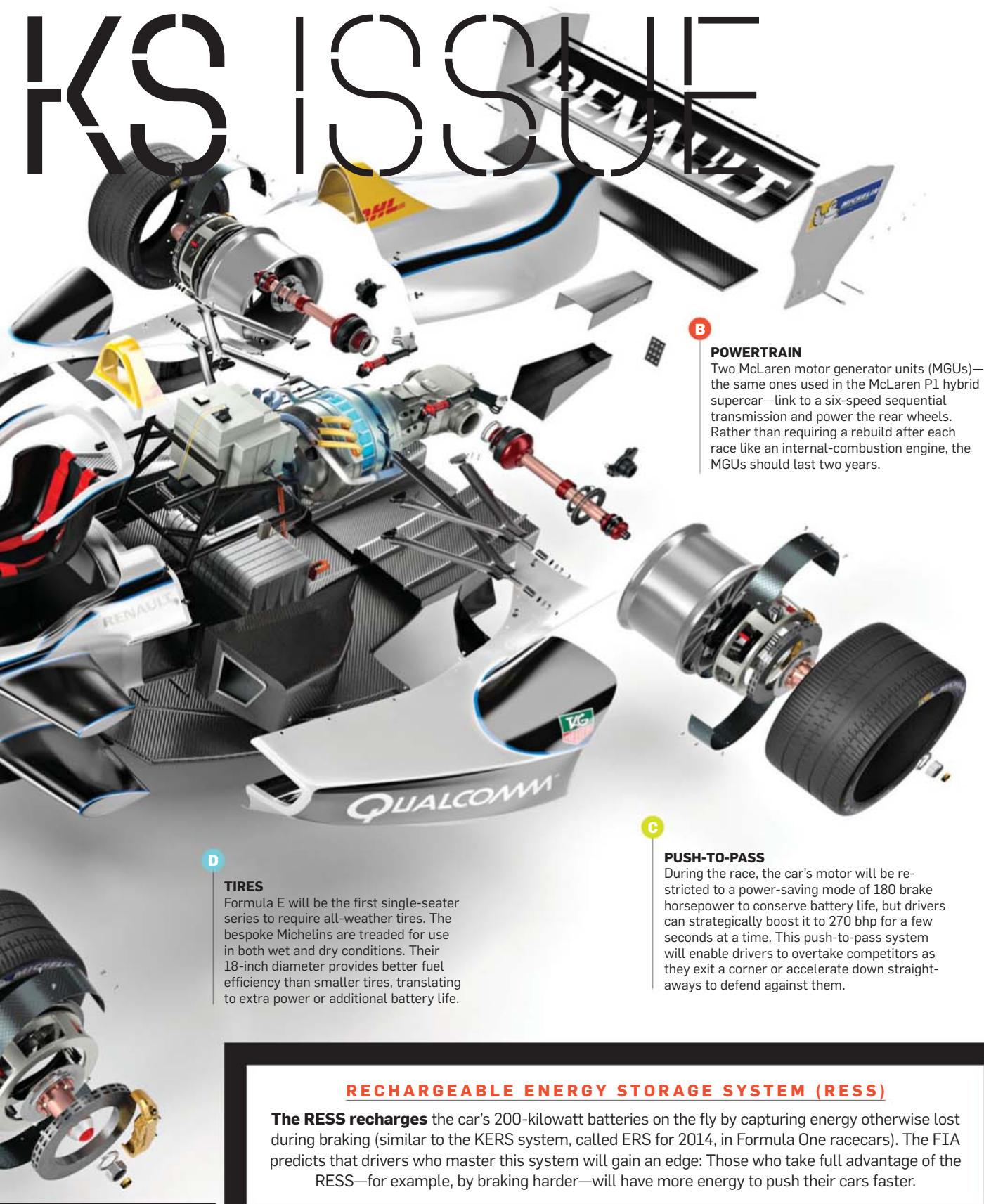
E

PIT STOPS

Each team has four vehicles, and each driver must make two pit stops to switch cars during the one-hour race. At speeds of 241.4 kmph, the batteries last about 30 minutes (and can't be swapped out). Qualcomm will adapt its Halo wireless charging to safety cars this year and to racecars in season two.



KS ISSUE



B

POWERTRAIN

Two McLaren motor generator units (MGUs)—the same ones used in the McLaren P1 hybrid supercar—link to a six-speed sequential transmission and power the rear wheels. Rather than requiring a rebuild after each race like an internal-combustion engine, the MGUs should last two years.

D

TIRES

Formula E will be the first single-seater series to require all-weather tires. The bespoke Michelins are treaded for use in both wet and dry conditions. Their 18-inch diameter provides better fuel efficiency than smaller tires, translating to extra power or additional battery life.

C

PUSH-TO-PASS

During the race, the car's motor will be restricted to a power-saving mode of 180 brake horsepower to conserve battery life, but drivers can strategically boost it to 270 bhp for a few seconds at a time. This push-to-pass system will enable drivers to overtake competitors as they exit a corner or accelerate down straight-aways to defend against them.

RECHARGEABLE ENERGY STORAGE SYSTEM (RESS)

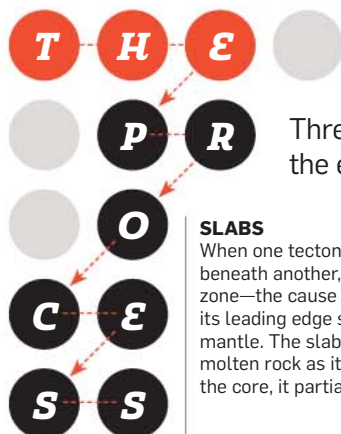
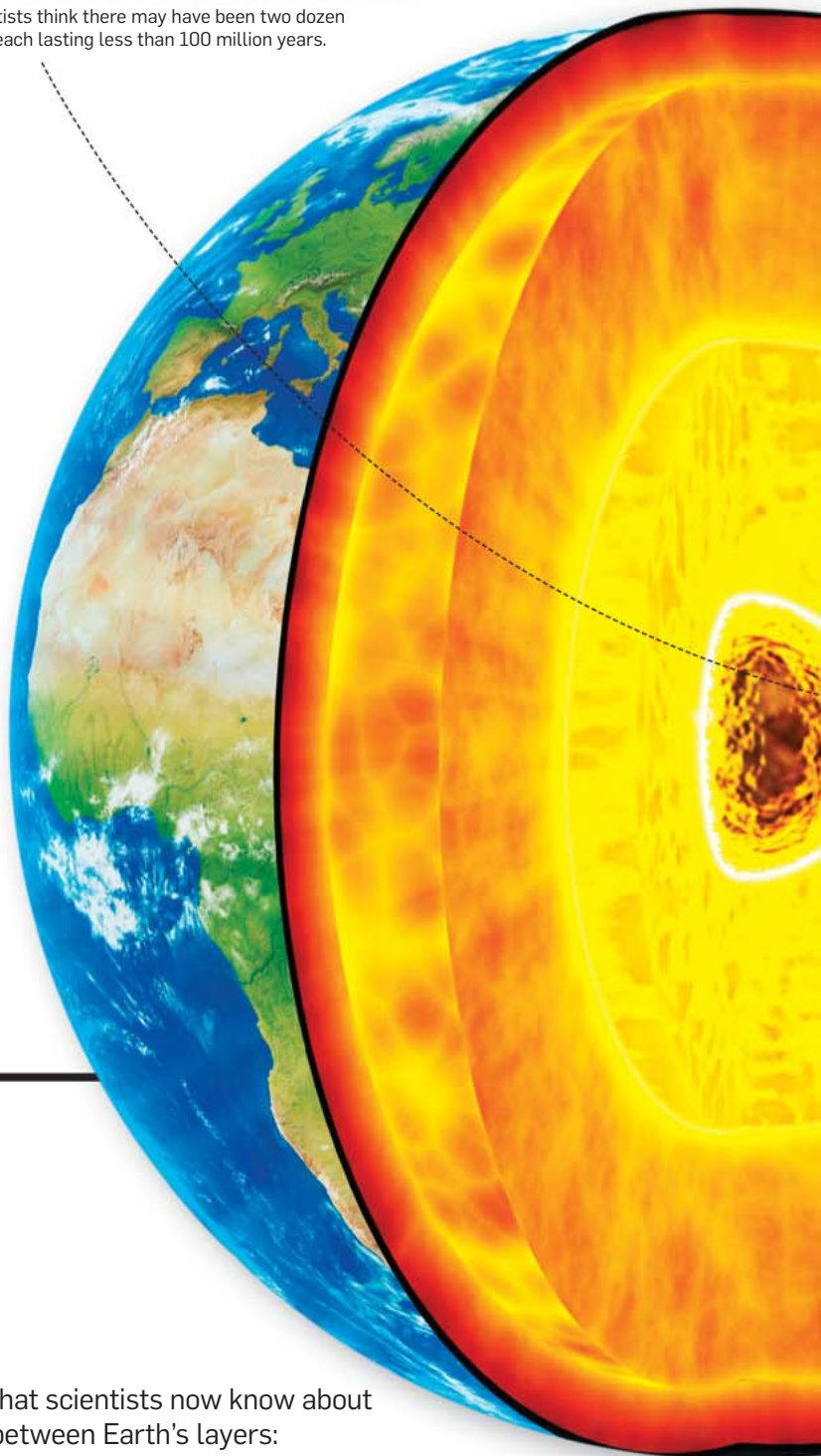
The RESS recharges the car's 200-kilowatt batteries on the fly by capturing energy otherwise lost during braking (similar to the KERS system, called ERS for 2014, in Formula One racecars). The FIA predicts that drivers who master this system will gain an edge: Those who take full advantage of the RESS—for example, by braking harder—will have more energy to push their cars faster.

In recent geologic time, scientists think there may have been two dozen mantle plumes worldwide, each lasting less than 100 million years.

THE INNER EARTH

Plate tectonics—the theory that explains the sinking, spreading, and slip-sliding of big chunks of Earth's surface—is a bedrock of geology. But it can't explain what happens to plates once they sink, or account for the forces that drive many of the planet's volcanic hotspots. Today, advances in seismology, geochemical analysis, and computer modeling have enabled researchers to collect a wealth of new geological data about our planet and form a complementary theory of what's going on beneath its surface.

By Valerie Ross



Three features describe what scientists now know about the exchange of material between Earth's layers:

SLABS

When one tectonic plate is forced beneath another, forming a subduction zone—the cause of many earthquakes—its leading edge sinks deeper into the mantle. The slab descends slowly, mixing molten rock as it goes, and as it nears the core, it partially melts.

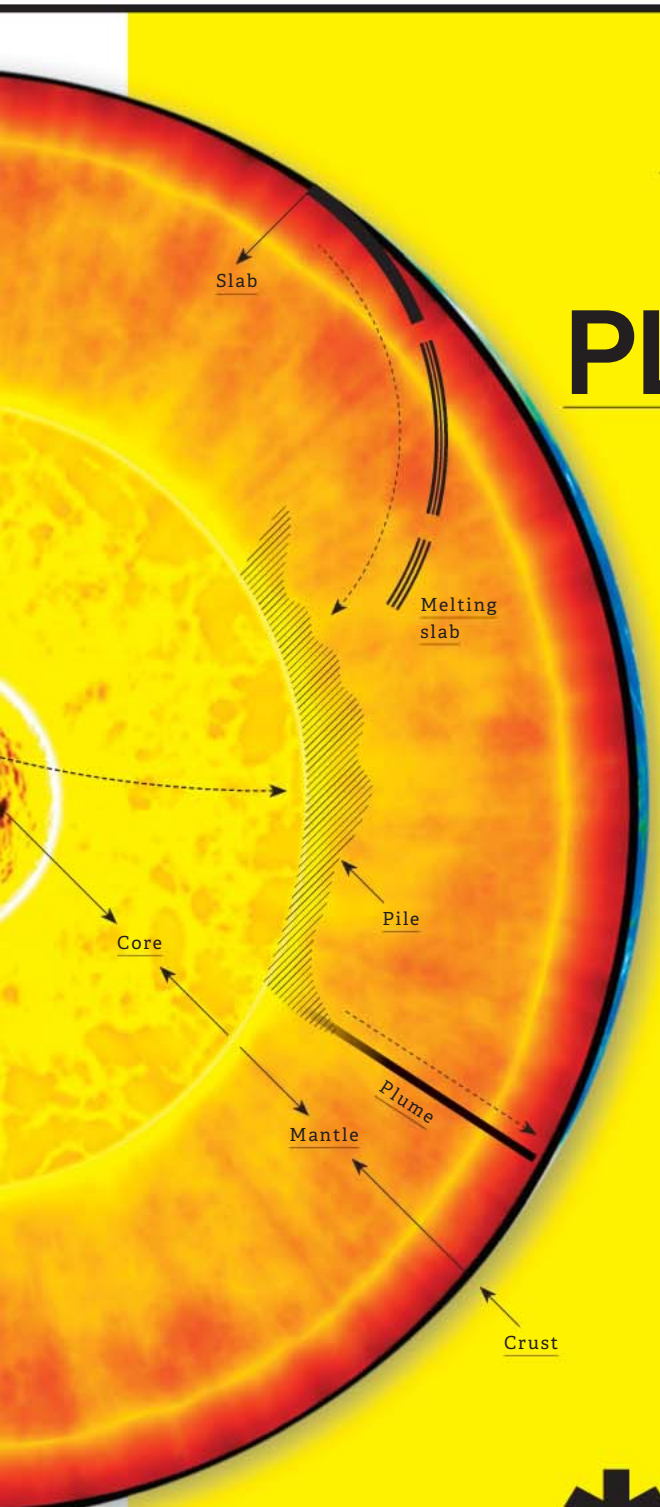
PLUMES

Most volcanoes begin in the relatively cool upper mantle and shoot up along the rims of tectonic plates. But geologists now think many of Earth's hotspots (in Iceland, for example) are powered by mantle plumes. These plumes rise in columns from the very bottom of the mantle, some 1,800 miles down, and carry heat from near the core to the crust.

PILES

Plumes originate along the edges of two vast areas—commonly known as piles—that lie opposite one another on the equator, one under Africa and the other under the South Pacific. Both piles contain material that seems to have remained in the deep mantle for about four billion years (perhaps because of its high iron content).

KNOW YOUR PLANET



CRUST

The relatively thin and cool crust forms Earth's surface.

TEMPERATURE: Ranges from surface temperature near the top to 871°C at the bottom

THICKNESS: About 8 km under the oceans and 40 km under the continents

COMPOSITION: Silicates that take the form of granite and basalt rocks

MANTLE*

Two thirds of the planet's mass, the mantle is the source of molten rock that rises to the surface during volcanic eruptions and when plates spread apart.

TEMPERATURE: About 871°C at the top and 2,204°C at the bottom

THICKNESS: Approximately 2,896 km

COMPOSITION: Largely silicate rocks containing more iron than those in the crust

CORE

The ultrahot, metallic core sits at the planet's center.

TEMPERATURE: About 2,204°C at the outer edge to 4,982°C at its center

THICKNESS: The outer core is 2,252.6 km thick. The inner core has a 1,236-km radius.

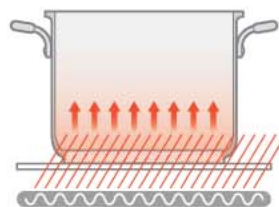
COMPOSITION: Predominantly iron, with some nickel and other elements; the outer core is molten, and the inner core is solid.

AS OF JANUARY, WE'VE GOTTEN CLOSER TO THE MANTLE THAN EVER: THE JAPANESE VESSEL CHIKYU DRILLED 1.9 MILES UNDER THE SEAFLOOR.



SIMPLY PUT

INDUCTION STOVETOP



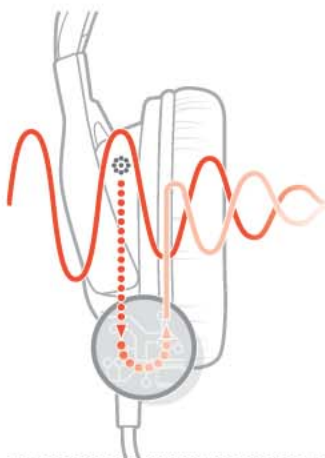
An induction cooking range is faster and has better temperature control than a gas or electric one—and yet, it never gets hot.

Inside the range, an electric current passes through copper coils, creating a magnetic field. The field interacts with the bottom of a cooking pot containing a ferromagnetic material such as iron or stainless steel. This causes the molecules in the cookware to move, producing heat.

SANDEEP RAVINDRAN

SIMPLY PUT

NOISE-CANCELING HEADPHONES

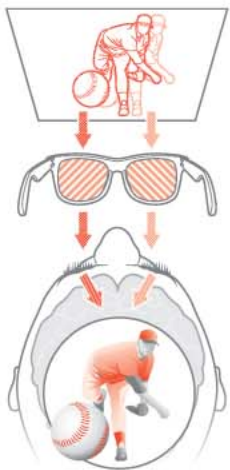


1. A microphone listens for ambient noise, such as traffic or chatter.
2. A circuit board inside the headphones generates a sound wave that opposes that of the noise.
3. The headphone driver plays that wave, neutralizing the clamor.

LILLIAN STEENBLIK HWANG

SIMPLY
PUT

POLARIZED 3-D GLASSES



1 The screen displays two images with different polarizations.

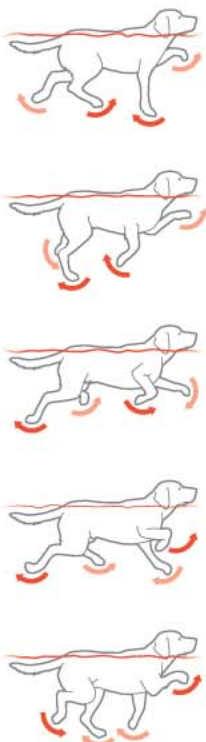
2 Glasses contain filters placed in opposite directions, allowing only one image to enter each eye.

3 The brain combines the two images to perceive depth.

JIA YOU

SIMPLY
PUT

DOGGIE PADDLE



In January, scientists showed with underwater video that dogs swim with movement more like a run than a trot (in which diagonally opposite legs move at the same time).

J. Y.

TRY IT YOURSELF!

Test out this method the next time you go swimming.

Star trackers and sun sensors determine Griffin's orientation.

PRIVATE MOON LANDER

By Rebecca Boyle

Next year, robots will land on the moon, competing for the Google Lunar XPRIZE. The contest offers \$40 million in rewards, including a \$20 million grand prize. Winning is fairly straightforward: Safely land a privately funded spacecraft, move it a third of a mile, and beam back HD-video "moon-casts." Completing the challenge by December 31, 2015, however, is anything but easy. Organizers have already extended the deadline by a year, and of the 33 teams that initially registered, only 18 remain. Astrobotic, an offshoot of Carnegie Mellon University, survives as a leading contender. The group has finished a two-spacecraft design—Griffin, a car-size lander, and a surface explorer called Red Rover. It has also booked space aboard a rocket that's scheduled to launch in October 2015. Here's how Astrobotic plans to take home the prize.

CHALLENGES

1 REACH THE MOON

A SpaceX Falcon 9 rocket will send Astrobotic's two-spacecraft stack on a trajectory toward the moon. From there, the four-legged aluminum lander, Griffin, will reach lunar orbit 4.5 days later.

2 LAND SOFTLY

Like an Apollo lander, Griffin will fire its main thruster to slow down and descend toward the moon. Four clusters of smaller thrusters, each fed by four spherical fuel tanks, will make minute course corrections to stick the landing.

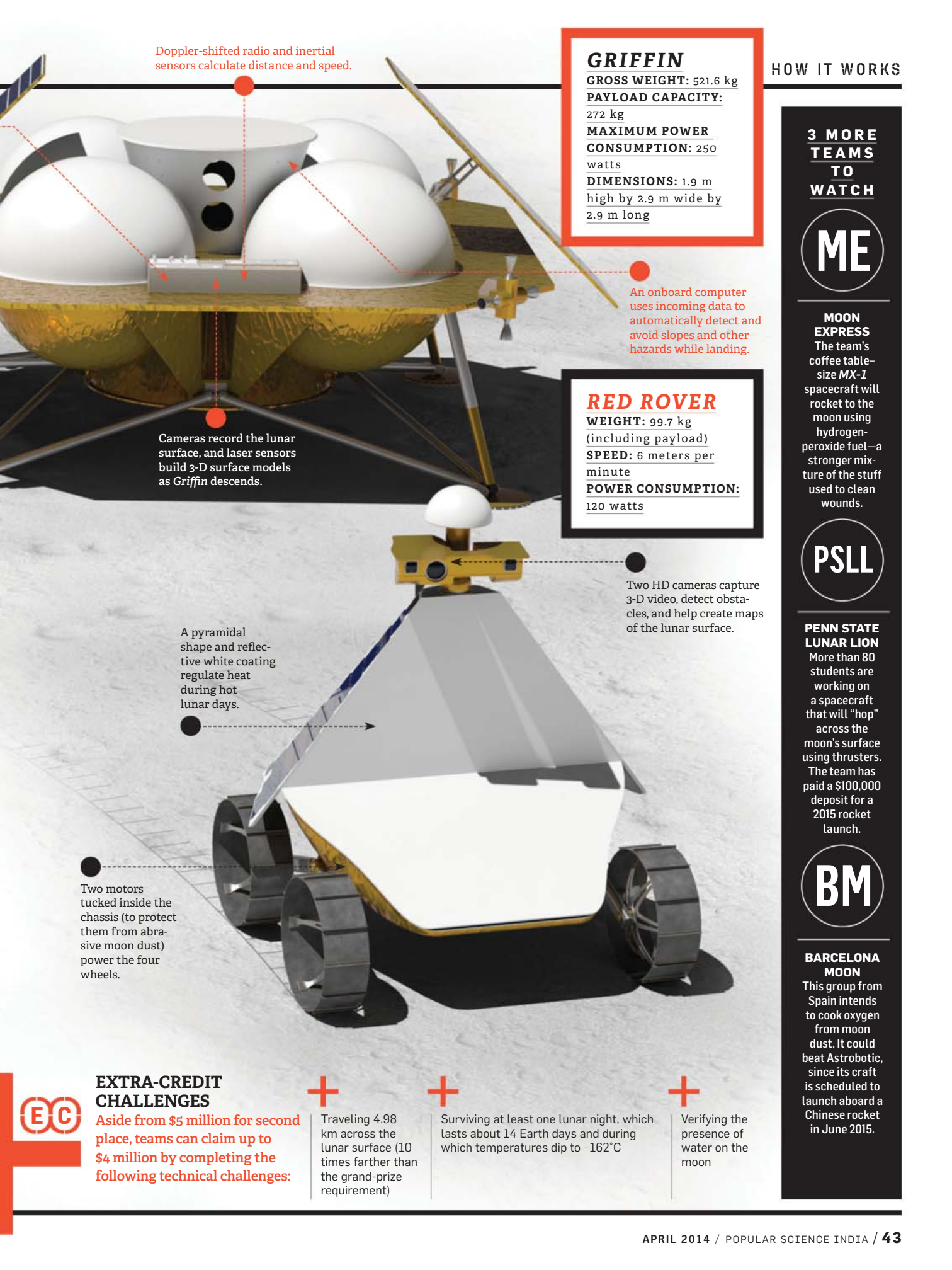
3 GET MOVING

Once Griffin safely touches down, Red Rover will drop from the lander's lower deck and begin its journey. Human drivers on Earth will steer it via joystick while monitoring 3-D camera footage. A passive rocker suspension system will keep all four wheels on the lunar surface at all times, allowing the craft to clamber over rocks and uneven terrain. Red Rover is also programmed to automatically avoid obstacles such as steep crater walls.

4 PHONE HOME

Red Rover will stream photos and video back to Griffin at five megabits per second (equivalent to cable Internet speeds), and Griffin will relay the data to Earth at a one-megabit-per-second clip (roughly as fast as DSL). Future rovers will talk directly to Earth to improve bandwidth—and shorten the laggy 10-second round-trip for packets of data.

TREVOR JOHNSTON



Doppler-shifted radio and inertial sensors calculate distance and speed.

Cameras record the lunar surface, and laser sensors build 3-D surface models as *Griffin* descends.

A pyramidal shape and reflective white coating regulate heat during hot lunar days.

Two motors tucked inside the chassis (to protect them from abrasive moon dust) power the four wheels.

GRIFFIN

GROSS WEIGHT: 521.6 kg

PAYLOAD CAPACITY:

272 kg

MAXIMUM POWER

CONSUMPTION: 250

watts

DIMENSIONS: 1.9 m

high by 2.9 m wide by

2.9 m long

An onboard computer uses incoming data to automatically detect and avoid slopes and other hazards while landing.

RED ROVER

WEIGHT: 99.7 kg

(including payload)

SPEED: 6 meters per

minute

POWER CONSUMPTION:

120 watts

Two HD cameras capture 3-D video, detect obstacles, and help create maps of the lunar surface.

EXTRA-CREDIT CHALLENGES

Aside from \$5 million for second place, teams can claim up to \$4 million by completing the following technical challenges:



Traveling 4.98 km across the lunar surface (10 times farther than the grand-prize requirement)



Surviving at least one lunar night, which lasts about 14 Earth days and during which temperatures dip to -162°C



Verifying the presence of water on the moon

HOW IT WORKS

3 MORE
TEAMS
TO
WATCH

ME

MOON EXPRESS

The team's coffee table-size *MX-1* spacecraft will rocket to the moon using hydrogen-peroxide fuel—a stronger mixture of the stuff used to clean wounds.

PSLL

PENN STATE LUNAR LION

More than 80 students are working on a spacecraft that will "hop" across the moon's surface using thrusters. The team has paid a \$100,000 deposit for a 2015 rocket launch.

BM

BARCELONA MOON

This group from Spain intends to cook oxygen from moon dust. It could beat Astrobotic, since its craft is scheduled to launch aboard a Chinese rocket in June 2015.

EC

A WIFFLE BALL PITCH

The Wiffle ball has been fooling batters since its invention in 1953, but scientists only recently learned why. Mechanical engineer Jenn Stroud Rossmann at Lafayette College placed the ball in a wind tunnel, measured airflow around it, and concluded that the shifting balance of forces inside and outside the ball is what makes it so devilishly hard to hit.

By Bjorn Carey

Illustration by Trevor Johnston

H

WHY NO H?

According to legend, the inventor, David N. Mullany, dropped the *h* so he wouldn't have to spend as much money on marketing materials.

NET FORCE

The strengths of the internal and external forces shift constantly while the ball is in flight. The net of the forces is what dictates the ball's path.

HOLES

The holes are on just one side. They disrupt airflow, increasing turbulence over that half of the ball.

EXTERNAL FORCE

More turbulence means less drag on that side, resulting in an upward "lift" force.

VORTICES

Air rushing into the holes creates vortices that whirl inside. The ball's orientation, spin, and velocity all affect how those vortices develop.

INTERIOR FORCE

Vortices create a force that can change the ball's direction. On faster pitches, the interior force typically overpowers the external force.

EXTERNAL FORCE

NET FORCE

INTERIOR FORCE

Ball's direction

Vortices

Airflow

THROW AN UNHITTABLE KNUCKLEBALL



Toss the ball at an easy speed, without spin, so the holes will face the batter upon release. In this orientation, the internal and external forces are at a perilous equilibrium: If the ball turns slightly—and it will—dominant airflow will shift and create a dramatic and unpredictable break.

Three Wiffle Ball Hacks



1

SCUFF

Scratching the smooth surface between the holes creates more turbulence on that side, strengthening the curve. Asymmetry is key, so scuff only the one side.



2

OPEN UP

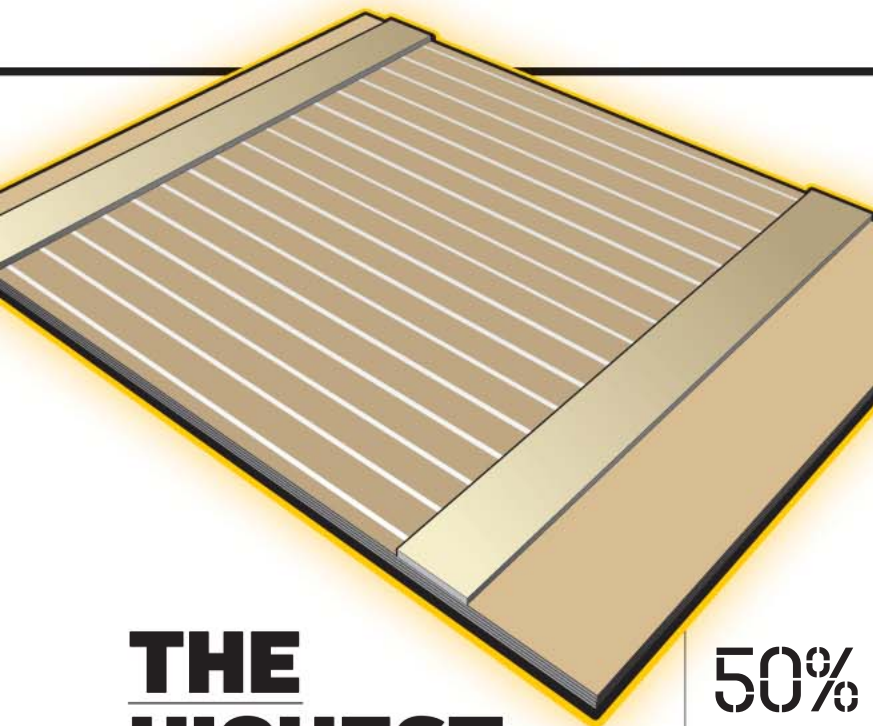
Enlarging the holes or smoothing their edges can increase interior airflow and make it the governing force, causing the ball to break toward the solid side.



3

BLOCK

Covering or deforming select holes can encourage multiple vortices of different magnitudes to form, leading to more dramatic curves.



THE HIGHEST-EFFICIENCY SOLAR CELL

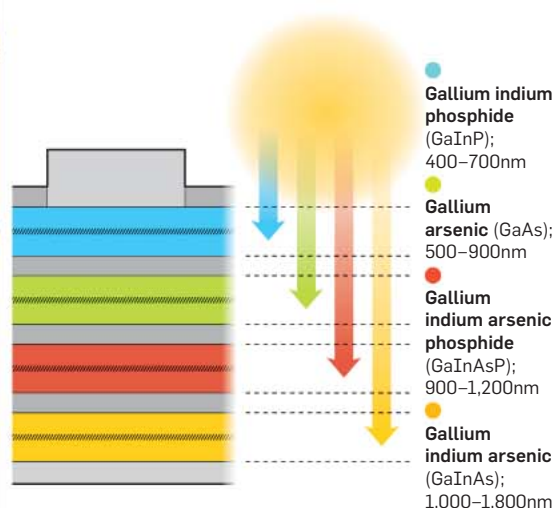
50%

The ultimate efficiency goal for solar-cell researchers

By Lillian Steenblik Hwang

Solar cells typically convert just 20 percent of incoming energy into electricity, in part because they capture only certain wavelengths of light. Researchers at Germany's Fraunhofer Institute for Solar Energy Systems have developed a solar cell that converts 44.7 percent—a new record. It consists

of a lens that concentrates sunlight onto four stacked subcells, each designed to absorb a distinct portion of the spectrum. The team estimates it will take them another two to three years to scale up the 5.2-millimeter prototype for use in solar-power plants.



1. Sunlight passes through a multifaceted lens known as a Fresnel. The lens focuses direct sunlight, delivering the power equivalent of 297 suns to the solar cell below.

2. The first subcell, made from gallium indium phosphide, captures photons from the shortest wavelengths of light. The subcells beneath it contain elements capable of capturing progressively longer wavelengths.

3. Each subcell consists of several semiconductor layers, which create an electric field. As photons enter, they excite electrons, freeing them from the subcell.

4. Once the freed electrons reach the top of the stack, a metal contact funnels them toward an output terminal as a direct current.

HOW TO MAKE "PINK SLIME"



INSPECT

Metal detectors and workers scan fat trimmings for bone and other debris.

A machine cuts the trimmings into small, uniform pieces.

GRIND

REFINE

A second, finer grinder removes sinew and cartilage.

A series of tubes warm the product to 102.5°F, a live cow's normal body temperature.

TEMPER

SEPARATE

A centrifuge spinning at 4,800 rpm separates meat from fat.

A puff of ammonium hydroxide raises the surface pH of the meat to inhibit microbial growth.

SANITIZE

FREEZE

The meat is frozen and formed into ½-inch pieces or 60-pound blocks.

There can be up to 11.34 kg of lean meat in the fat trimmings of the average beef cow. BPI, a meat-processing company, pioneered the process of extracting it. Meat-product manufacturers use this lean finely textured beef—a.k.a. pink slime—to create packaged ground beef with specific lean-to-fat ratios. L.S.H.

SURGICAL SNAKEBOT

By Erik Sofge

Steer

A surgeon steers the Flex System into the body with a haptic controller, which translates the robot's contact with tissue into varying degrees of resistance in the joystick.

Sense

The robot's endoscopic "head," or distal end, features a high-definition video camera ringed by six LEDs (footage appears on a nearby monitor).

Slice

The robot has a port on either side of its camera tip, where tools for grasping and cutting tissue can be inserted. They are threaded into the Flex System once it's in place.

Surgery has always been synonymous with incisions. But the new snake-inspired Flex System from Medrobotics could reduce bloodshed and hasten healing by traveling through a convenient (if unsettling) alternative: a natural orifice, such as the mouth.

During a Flex procedure, the surgeon stands or sits within arm's reach of the patient and a video console, and alternates between

steering the robot with a joystick and manually operating the instruments threaded through its tip. Since the bot curves and pivots to maneuver around tissue and organs, Medrobotics claims it's more versatile than laparoscopy, which often requires multiple punctures to insert a camera and tools.

The company is now submitting Flex for approval in the U.S. and Europe for head and neck procedures, such as the removal of throat tumors. But the snakebot's ultimate destination is the abdomen, via a small incision—or a private orifice. It's an approach that, while distressing to imagine, could revolutionize surgery.

Slither

The snakebot locks in each turn as it pushes forward, its mechanical linkages automatically flexing and straightening to follow anatomical curves of almost 180 degrees.

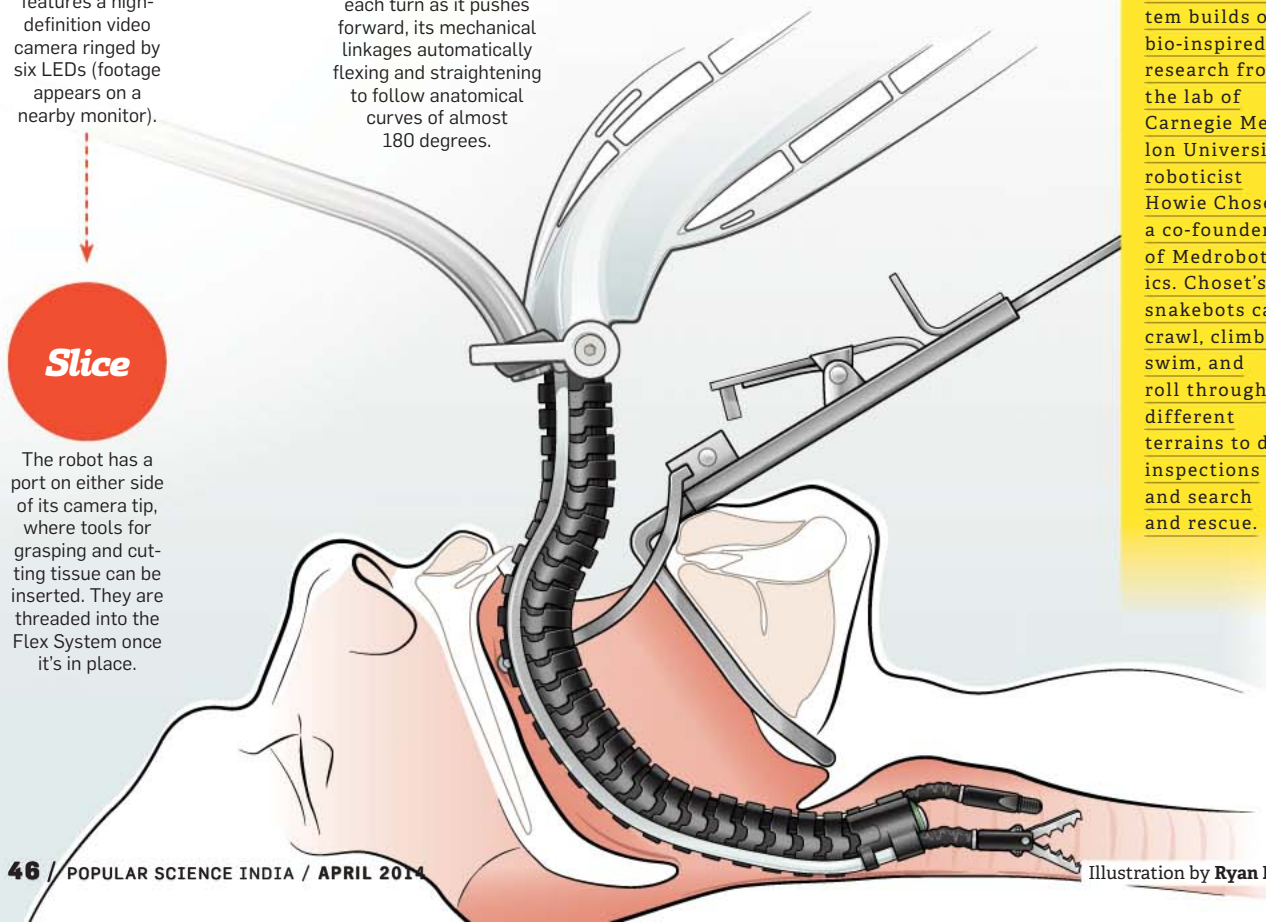
QUICK HISTORY

THE COMPETITION

For more than a decade, the only robot cleared for general surgery has been Intuitive Surgical's da Vinci Surgical System. It costs up to \$2.3 million and uses remote-controlled manipulators for precise operation inside the body—but it needs as many as six entry points to reach a tumor.

THE INSPIRATION

The Flex System builds on bio-inspired research from the lab of Carnegie Mellon University roboticist Howie Choset, a co-founder of Medrobotics. Choset's snakebots can crawl, climb, swim, and roll through different terrains to do inspections and search and rescue.



F

E

Since electronic cigarettes hit the market in 2007, yearly sales have reached \$1 billion in the U.S. Although they're popular, it's still unclear how safe they are. Last year, a study from an international group of scientists showed that the toxins in e-cigarette vapor are 9 to 450 times lower than in tobacco smoke. The Food and Drug Administration is still determining its regulatory stance. It's sponsoring more research while sorting out its position.



Proportion of
deaths in the
U.S. caused by
tobacco ciga-
rette smoking.

A

B

D

SE
air

**IN THE
END**



CHEMICAL WEAPONS

prohibiting the manufacture and stockpiling of these arms. The Geneva Protocol had already banned their use, and with good reason: Chemical weapons are classified by the U.S. military as weapons of mass destruction because they're nothing less than airborne poison—delivered by rocket—capable of killing thousands of people in minutes. **VERONIQUE GREENWOOD**



ON SEPTEMBER 16, 2008, Carl Pike, the deputy head of the Drug Enforcement Administration's Special Operations Division, watched live video feeds from a command center outside Washington, D.C., as federal agents fanned out across dozens of U.S. cities. In Dallas, a team in SWAT gear tossed a flash-bang grenade into a suburban home and, once inside, discovered 2.7 kg of cocaine behind a stove, and a stockpile of guns. At a used-car dealer's house in Carmel, Indiana, agents pulled bricks of cocaine from a secret compartment in his Audi sedan, while state troopers dragged a stove-size safe onto the lawn and went at it with a sledgehammer.

RADIO TECNICO

HOW THE ZETAS CARTEL TOOK OVER MEXICO
WITH WALKIE-TALKIES

BY DAMON TABOR

In the coming weeks, the net widened to include caches of assault rifles, a Mexico-bound 18-wheeler with drug money hidden in fresh produce, and a crooked Texas sheriff who helped traffic narcotics through his county. In Mexico City, a financier was arrested for laundering drug money through a minor-league soccer team named the Raccoons (and an avocado farm). After one especially large bust, when it came time for a “dope on the table” photo, there was in fact no table big enough to support the thousands of tightly bundled kilos of confiscated cocaine. They had to be stacked in the back parking lot of a police station.

The raids and arrests were the final stage of a DEA-led investigation called Project Reckoning—18 months, 64 cities, 200 agencies—intended to cripple Mexico's Gulf Cartel. Over the past two decades, the organization had built a drug empire that spanned across Mexico and into the U.S. It had become pervasive, hyper-violent, brazen. Cartel operatives had smuggled billions of dollars' worth of narcotics into the U.S. They had assassinated Mexican politicians and corrupted entire police departments. One of the



1



2



organization's leaders had famously brandished a gold-plated .45 at two agents from the DEA and FBI traveling through northeastern Mexico. The cartel had even formed its own paramilitary unit, a band of former Mexican police and special-forces soldiers called the Zetas, to seize territory and dispatch rivals. The notorious syndicate became known as La Compañía, or The Company.

Project Reckoning, authorities proclaimed, had dealt La Compañía's business a "substantial blow". The DEA's Pike likened it to taking out 64 cartel-owned Walmarts. And once all the doors had been kicked in, the haul was indeed staggering: \$90 million in cash, 27.66 metric tonnes of narcotics, and enough weapons to equip an insurgency. Among the 900 people rounded up across the U.S. and Mexico, the Justice Department indicted dealers, transporters, money counters, teen gangsters, and even the owner of a Quiznos franchise. One of those swept up in the net was a 37-year-old resident of McAllen, Texas, named Jose Luis Del Toro Estrada. He seemed, at first, not particularly significant—a luckless guppy caught swimming with sharks. His arrest barely warranted mention in the local paper. His house, a well-maintained white-brick rancher with an arbor of pink flowers over the front door, contained no cocaine or caches of AK-47s. He lacked an extensive rap sheet and in fact seemed to have no criminal record at all. On the outskirts of McAllen, he ran a small, non-descript shop that installed car alarms and sold two-way radios.

In the weeks that followed, a different picture began to emerge. Del Toro Estrada was neither capo nor killer, but he played a critical role in The Company. According to federal prosecutors, the shop owner—who went by the alias Técnico—had served as The Company's communications expert. He was the cartel's in-house geek, the head of IT, and he had used his expertise to help engineer its brutal rise to power. Del Toro Estrada had not only set up secret camera networks to spy on Mexican officials and surveil drug stash houses, but he also built from the ground up an elaborate, covert communications network that covered much of the country. This system enabled the cartel to smuggle narcotics by the ton into the U.S., as well as billions of dollars in drug money back into Mexico. Most remarkably, it had provided The Company with a Gorgon-like omniscience or, according to Pike, the ability to track everything related to its narcotics distribution: drug loads but also Mexican police, military, even U.S. border-patrol agents. That a cartel had begun employing communications experts was likely news to most of law enforcement. That it had pulled off a massive engineering project spanning most of Mexico—and done so largely in secret—was unparalleled in the annals of criminal enterprise.

THE GODFATHER OF THE GULF CARTEL was not a drug kingpin but a *contrabandista* named Juan Guerra who began smuggling bootleg whiskey into Texas during Prohibition. In the decades that followed, Guerra expanded into prostitution and gambling along the Rio Grande, building out a small but profitable criminal enterprise. The business eventually passed to Guerra's nephew, Juan Garcia Abrego, who in the mid-1980s identified an opportunity. Several years before, American drug agents had started to crack down on cocaine-supply lines from Colombia into Florida. Garcia Abrego approached the besieged Colombians with an offer: Instead of taking a transporter's customary small cash percentage, he would guarantee cocaine deliveries through Mexico into the U.S. in exchange for 50 percent of each load. It was a riskier but immensely more profitable arrangement, and it eventually birthed one of Mexico's first major narcotics organizations, the Gulf Cartel. In 1995, the FBI placed Garcia Abrego on its Ten Most Wanted list, the first drug trafficker to earn the distinction.

Garcia Abrego led the cartel until 1996, when he was arrested by Mexican police outside the city of Monterrey. His successor was a jug-eared, mercurial former auto mechanic and aspiring gangster named Osiel Cardenas Guillen, a.k.a. The Friend Killer. In the late 1990s, hoping to surround himself with an impenetrable security ring while also creating a lethal mercenary force, Cardenas Guillen formed a paramilitary unit composed largely of defectors from the Mexican police and military. Some, like Heriberto Lazcano Lazcano, a.k.a. The Executioner, were commandos from an elite

TECNICO WAS THE CARTEL'S IN-HOUSE GEEK,
AND HE USED HIS EXPERTISE TO HELP
ENGINEER ITS BRUTAL RISE TO POWER.



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1

Jose Luis Del Toro Estrada, a.k.a. Tecnico, lived for years as an agent of the Zetas cartel on a quiet street in McAllen, Texas. He is credited with masterminding the cartel's radio network, which spanned from the U.S. border to Guatemala.

2

Cities in northeastern Mexico such as Ciudad Victoria have become hotspots for cartel violence. In any given town, the Zetas use street-corner spies armed with walkie-talkies to mount surveillance.

3

Del Toro Estrada maintained a small radio-equipment shop in McAllen, presumably as a cover. The shop still stands, though a recent visit found it devoid of equipment, ringed by closed-circuit cameras, and somewhat hostile toward unexpected customers.

4

Though the Zetas' radio network functioned predominantly in Mexico, most experts say it could have worked just over the U.S. border as well. Using software, the Zetas could scramble their transmissions, to thwart any eavesdroppers.

American-trained airborne special-forces unit. It was an epochal moment in cartel development. The Zetas—who reportedly took the name from their first commander's military radio call sign, Z1—were highly trained and brutally efficient. They built remote narco-camps to train new recruits in military tactics, weapons, and communications. They recruited other special-forces soldiers from Guatemala, known as Kaibiles, a name derived from an indigenous leader who bedeviled Spanish conquistadores in the 16th century. They secured new drug routes, attacked other gangs, and even instituted an accounting system—the Zetas kept detailed ledgers and employed a dedicated team of number crunchers—that has since become nearly as legendary as the group's capacity for bloodletting. "Before the Zetas, it was basically low-quality foot soldiers and enforcer types," says Robert Bunker, a visiting professor at the U.S. Army War College's Strategic Studies Institute. "What the Zetas brought to the table was that [military] operational capability. The other cartels didn't know anything about this. It revolutionized the whole landscape."

It's impossible to say exactly why the Zetas chose to build the radio network, but given their military and law-enforcement background, it seems likely that Z1 and his capos understood that a widespread communications system would provide a crucial competitive edge over other cartels. Radio was the clear choice. Unlike cell phones, which are expensive, traceable, and easily tapped, radio equipment is cheap, easy to set up, and more secure. Handheld walkie-talkies, antennas, and signal repeaters to boost transmissions are all available at a good radio shop or from a Motorola distributor. A radio network could provide communications in many of the remote areas in Mexico where the cartel operated. And, if they suspected law enforcement eavesdropping, the cartel's drug smugglers and gunmen could easily switch frequencies or use commercially available software to garble voice transmissions.

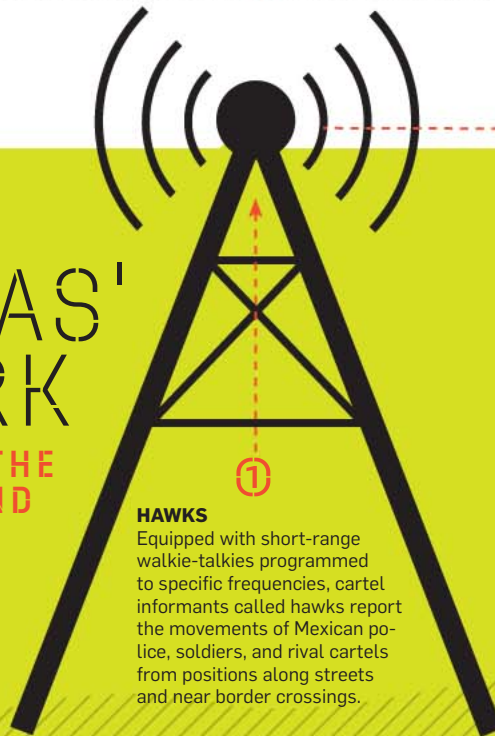
How Jose Luis Del Toro Estrada was tapped to develop the covert radio network also remains a mystery, but as his system grew, it supplied the Zetas with what's called a command-and-control capacity. "It essentially linked all the different members of the cartel—the people doing the trafficking and the people doing the protection—so there was a communication between them," says Pike, the DEA special agent. Armed with handheld radios, the cartel's street-corner *halcones*, or hawks, could help commanders avoid arrest by alerting them whenever police set up checkpoints. A midlevel boss in Nuevo Laredo could monitor a semitruck carrying several tons of cocaine as it trundled across the border into Texas. Most crucially, Zetas gunmen could use the system to attack and seize *plazas*, or smuggling corridors, held by other drug gangs.

"With a network like this, you can take what resources you have and maximize them for effectiveness," says Bunker. "If [the Zetas] are going into a different cartel's area, they can bring resources in," such as weapons, vehicles, and reinforcements. "It means for every one enforcer or foot soldier, you get a multiplier effect. From a command-and-control perspective, it's phenomenal."

With the advantage of Del Toro Estrada's radio network, The Company grew quickly, dominating rival groups—but lasting relationships are fleeting in the criminal underworld. In 2010, after several years of internal friction, the Gulf Cartel and the Zetas severed ties. (Causes of the split are murky, but many analysts say the breaking point occurred when the Gulf Cartel kidnapped and killed the Zetas' chief of finance after failing to persuade him to switch allegiance.) In the years that followed, the influence of the Gulf Cartel, once the most powerful in Mexico, waned dramatically. At the same time, the influence of the Zetas grew rapidly. Their business portfolio expanded to include drug running as well as kidnapping, human smuggling, pirating DVDs, and even selling black-market oil. In some regions, they began to operate with such

INSIDE THE ZETAS' NETWORK

BREAKING DOWN THE CHAIN OF COMMAND



HAWKS

Equipped with short-range walkie-talkies programmed to specific frequencies, cartel informants called hawks report the movements of Mexican police, soldiers, and rival cartels from positions along streets and near border crossings.

ANTENNAS

A string of antennas concealed on rooftops, towers, and in trees—and often hijacked from legitimate businesses—receive and transmit walkie-talkie transmissions from Zetas personnel.

REPEATER

A repeater receives radio traffic, then amplifies the signal to travel over greater distances or obstacles like mountains, allowing cartel members to communicate across dozens of miles. By separating incoming and outgoing signals, a duplex repeater lets different units—hawks, drug runners, gunmen—talk over a single channel.

impunity that their authority eclipsed that of the Mexican government itself. The Zetas' military training and ultraviolent tactics were crucial for propelling their rise to power, but one other factor was essential: After splitting from the Gulf Cartel, it was the Zetas who maintained control of the radio network.

AFTER PROJECT RECKONING, Del Toro Estrada became a ghost. Neither the DEA nor the Justice Department would discuss his case. Letters to the Reeves County Detention Complex in West Texas, where he was housed for a time, remain unanswered. Before his arrest, though, Del Toro Estrada had lived openly in Texas for at least a decade as a resident alien with a green card. He ran a small radio shop called V & V Communications that sold walkie-talkies and other equipment. He and his wife owned several modest properties around McAllen, including a nicely wooded *ranchito* with a small horse stable and a swimming pool. An American flag hung from the front porch.

Many details about Del Toro Estrada's involvement with The Company remain opaque. It's unclear whether he was recruited in McAllen or placed there as an operative. Also unclear is whether he was a formally trained engineer or some kind of criminal autodidact who spent years steeping himself in the finer points of radio-broadcast engineering. Either way, he did not match the profile of a typical cartel member. "He wasn't an assassin. He was a geek, a technician," says a former federal counter-narcotics official who now runs an intelligence consulting firm in Arlington, Virginia.

Yet a technically savvy radio operator living near the U.S. border was precisely what the Zetas required. According to the former official, the Zetas first began building the radio network in Matamoros, a border city across from Brownsville, Texas,

around 2004. Del Toro Estrada probably served as the project's overseer. Initially, the small cluster of radios and antennas were tools to monitor police and other drug gangs. But then-president Felipe Calderón deployed troops and tightened security around air and sea routes into Mexico. With its ports of entry blocked, the cartel looked south and began establishing a strong presence in Guatemala. The country's 965 km of remote, porous border abutting Mexico made it an ideal overland entry point for narcotics. Drug runners could land multi-ton cocaine loads from Colombia at remote jungle airstrips in northern Guatemala and truck them across the border; at least 125 road entries allow vehicles to pass without inspection. From there, they would drive loads north to busy U.S. ports such as El Paso. The route was costly and logistically complex, so around 2006, the Zetas began expanding the radio network to help manage it: first along the Texas border, then down the Gulf Coast to Guatemala, and finally into Mexico's interior.

In any new city where the cartel wished to expand, Del Toro Estrada's first step would have been to map the local radio spectrum. Identifying who operated on what frequencies and which had the lightest traffic would preclude, for example, a local taxi company's radio chatter from disrupting a coordinated attack on a police station. In urban areas, Del Toro Estrada often affixed a cartel antenna to an existing commercial radio tower. He also hijacked radio repeaters—devices that receive and boost radio signals—from companies like Nextel and reprogrammed the equipment to use the cartel's preselected, low-volume frequencies. (Nextel maintains both cellular and, for its push-to-talk phones, radio networks). In at least one location, Del Toro Estrada installed a repeater on the roof of a Mexican police station, either a brazen display of the cartel's impunity or a signal of the department's corruption.

POWER

In urban areas, electricity tapped from municipal lines or building outlets powers the array of antennas and repeaters. In remote locations, technicians wire the equipment to car batteries or solar panels with high-capacity battery banks.

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⑤

CONTROL

At the communications headquarters, cartel members use commercial radio-communications software to manage thousands of walkie-talkies connected to the network: disabling handsets as Zetas soldiers are killed or captured, connecting users in different cities, relaying messages between cells, and adding new handsets as the network expands. Digital inversion software helps prevent Mexican law enforcement from listening in.

④

REGIONAL COM CENTERS

Semiautonomous regional communications centers—at least one of which was hidden in a suburban home—are equipped with networked laptops, central processors, and digital receivers to help coordinate the Zetas' local communications traffic.

⑦

BOSSES

Communications to top leaders are transmitted over a "command-and-control" frequency separate from those for daily operations.

⑥

GUNMEN

Tipped off about a rival cartel moving through its territory, Zetas foot soldiers armed with assault rifles, rocket-propelled grenades, and handheld radios use the network to orchestrate attacks involving several tactical units and multiple street blockades. The gunmen also likely use the system to coordinate prison breaks and assaults on government forces.

⑧

SMUGGLERS

Cartel bosses track drug-laden semitrucks transiting Mexico from Guatemala, then monitor their passage across border crossings like El Paso, Texas. In remote border areas, Zetas spotters use walkie-talkies to observe the movements of U.S. Border Patrol, then direct smugglers into the U.S. Cartel drug loads are then often transported to urban stash houses, repackaged for street sale, and then sold to a network of distributors across the country.

Expanding into more remote areas, like the jungle in southern Veracruz state, was more technically challenging: Towers had to be built atop high vantage points—a volcano's summit, for example—to ensure surrounding hills or other natural obstacles didn't block transmissions. Del Toro Estrada then installed repeaters and antennas on top of the tower, and in some instances, the structure was painted a dark green to camouflage it amid the foliage. To provide power, he wired the equipment to car batteries or, in many cases, photovoltaic solar panels. In Veracruz, a string of about a dozen tower installations provided a 160.9-km radius of communications capability—meaning the Zetas could track anything that moved, whether encroaching Sinaloa cartel gunmen or military convoys, in at least 10 towns and cities.

"It was just a constant flow of information," Pike says. "I equate it to the scene in *Black Hawk Down* when the chopper's taking off from the military base and the child up on the mountain with the telephone calls down and says, 'They're coming'."

As subnetworks went live in new areas, Del Toro Estrada daisy-chained them together into a larger, interoperable system.

This ability to link different units of the cartel was the network's strength, more than anything else. With commercial software from companies like Motorola, he could remotely manage thousands of walkie-talkies at one time. If a frequency in one area became too congested, he could switch users' radios to another. If a local boss in Matamoros had to coordinate a drug load with someone in Monterrey, Del Toro Estrada could connect them. If Zetas were captured, he could disable their handsets to thwart eavesdroppers. He also used digital inversion software, which scrambles radio transmissions into garbled, R2-D2-like squawking. The cartel even established regional command centers to manage some of its communications. In Coahuila state, Mexican soldiers raided a Zetas-occupied home that contained networked laptops, 63 digital walkie-talkies, a central processing unit to remotely control repeaters, and a digital radio that communicated with airplanes.

By 2008, Del Toro Estrada's infrastructure was operational in most states in Mexico (and likely in the U.S. borderlands as well). Local bosses chipped in for equipment, and the Zetas maintained ledgers detailing outlays for communications gear. Del Toro Es-

trada himself employed a team of specialists—his own cartel Geek Squad—to research new technology and program equipment. The network's architecture, like the nodes of routers that undergird the Internet, was resilient: If the Mexican military knocked out one tower, traffic could likely be routed through another. And it was, relatively speaking, cheap: The Company probably spent tens of millions of dollars building the network—a capital investment that would have paid for itself with the delivery of one large cocaine shipment into the U.S.

THE ZETAS COULD TRACK
ANYTHING THAT MOVED,
WHETHER ENCROACHING
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OR MILITARY CONVOYS.

ACTING AS A SNITCH WOULD HAVE MADE TECNICO A MARKED MAN, SO HE MAY HAVE DISAPPEARED INTO WITNESS PROTECTION.

"This thing was huge," the former official says of the cartel's communications system. "It was extensive, and it was interconnected. It was the most sophisticated radio network we'd ever encountered."

To manage a system of this size, Del Toro Estrada likely required a base of operations. His McAllen radio shop, V & V Communications, could have been an ideal location. It was unremarkable, close to the border, and, with radios purportedly for sale to the buying public, it provided a veneer of legitimacy.

The building—a white, single-story box with mirrored windows—still sits on a barely trafficked side street on the outskirts of the city. A 30-foot antenna tower juts from the roof. Customers must buzz in through the locked front entrance. A surveillance camera monitors the door; two more cover the store's interior. Inside, there are no handheld radios on display, no repeaters, no cables or chargers—no inventory at all, save for a few aged and disused radio-equipment pamphlets in a dusty glass case. The woman working the counter speaks only Spanish, and she seems neither prepared nor pleased to have visitors. On her business card is a nonworking email address and a website that does not exist.

AMERICAN OFFICIALS HAVE NOT publicly discussed the Zetas' radio network, but it's obvious there's an inverse relationship between it and the stability of the Mexican state. The larger the network grew, the more imperiled the state became. The flow of drugs north enabled a flow of cash south, which the cartel could use to buy off police, politicians, and public officials, as well as to hire new recruits and purchase guns—lots of guns. In 2008, soldiers raided a Company stash house containing the largest weapons cache seized in Mexican history: 500 handguns and assault rifles, a half-million rounds of ammunition, 150 grenades, seven .50-caliber sniper rifles, an anti-tank rocket, and 14 sticks of dynamite.

In recent years, the specter of midday combat in Tamaulipas, where the Zetas were battling their former employers for control, has grown increasingly common. In 2010, Zetas gunmen kidnapped and executed 72 Central American migrants, perhaps because they feared the Gulf Cartel might have hidden newly recruited assassins among them. That July, a heavily armed contingent of Zetas in Nuevo Laredo used an elaborate system of narco-blockades, or stolen trucks and buses parked in intersections, to funnel rivals into deadly ambushes. After a running, midday shootout that lasted hours, authorities recovered among the assault rifles and dead bodies a number of walkie-talkies—a sign, very likely, of Del Toro Estrada's handiwork. The governor of Tamaulipas soon declared the region "ungovernable."

With the Zetas at the center of the violence, the Mexican military decided to strike back at their most valuable asset: the radio

The Mexican military has cracked down on the Zetas' radio network. But it's resilient. For every tower the military takes down, the cartel could erect another in its place.

network. Battalions of troops were dispatched, and the military began attacking the system, probably aided by DEA-supplied intelligence directly from Del Toro Estrada, who began cooperating with the agency after his arrest and provided information about the system's infrastructure. During one operation in 2011, Mexican marines discovered several 18-wheelers housing mobile communications systems in Veracruz. Another operation spanned four states and resulted in an astonishing haul: 167 antennas, 155 repeaters, 71 computers, 166 solar panels and batteries, and nearly 3,000 radios and Nextel push-to-talk phones. Later, marines discovered a 91.4-meter-tall antenna tower by a major highway.

After the raids, masked soldiers posed with enough seized equipment to supply several Radio Shacks, while a military spokesman announced the disruption of the Zetas' "chain of command and tactical coordination." This was perhaps true, but the cartel also simply reinstalled towers and antennas once the military pulled out. It's also possible that the organization had conscripted a skilled, though unwilling, workforce to keep its radio network functioning after Del Toro Estrada's arrest.

Since 2009, reports have surfaced of communications specialists and engineers disappearing across the country. In one of the first known cases, nine Nextel technicians were kidnapped from a hotel in Nuevo Laredo. The men had planned to work in the area for several months expanding the company's spoty radio coverage, said Amalia Armenta, the wife of one of the victims. On June 20, she says, they were taken in the middle of the night by armed gunmen. None of them has been located. At least 27 other engineers and specialists from companies like IBM, ICA Fluor Daniel, and Mexico's state-run oil company Pemex have also since disappeared. Even without their chief radio architect, the Zetas were not going to give up one of their prized assets easily.



In remote areas, Zetas operatives would wire their equipment to solar panels for power. The network was so extensive it enabled communication even in locations without cellular service.



BY 2011, DEL TORO ESTRADA was being held in the federal detention center in Houston, a hulking granite edifice in the city's downtown that houses about 1,000 inmates. Most await trials or sentencing in the federal district court several blocks away. On May 11, Del Toro Estrada appeared before a federal judge for a final sentencing hearing, and then on June 21, 2012, after serving less than four years for having built one of most elaborate criminal infrastructure projects in history, he walked out of the prison's grim sprawl into the bright Texas sun. He had pleaded guilty to one charge of conspiracy to distribute cocaine, but while in custody, the prosecutors had offered to seek a lighter sentence in exchange for information about his former employers. Acting as a snitch would have made him a marked man, so following release, Del Toro Estrada may have disappeared into witness protection. He also may have fled back to Mexico, although this would have almost certainly made him more vulnerable to the cartel's reach. Or, perhaps he and his wife decided to hide in plain view. Four months after his release, the couple's white-brick rancher in McAllen still appeared occupied.

It's also plausible that the Zetas, increasingly under pressure by both rival cartels and the Mexican government, had been forced to concentrate on bigger problems. In July 2011, Mexican authorities arrested a top Zetas commander named El Mamito and soon nabbed another, who called himself El Taliban. A year later, soldiers stumbled upon the Zetas' top commander, Heriberto Lazcano Lazcano, at a small-town pickup-baseball game in Coahuila state. After a gunfight, they shot and killed him, along with two bodyguards. He was, by most estimates, the most high-profile narco to fall in the drug war, and the government proudly trumpeted his death as an important victory—one that dimmed somewhat after a contingent of gunmen spirited his body from the funeral home just hours after his death. In mid-July 2013, his successor, Miguel Angel Treviño Morales, was arrested in Tamaulipas, reportedly with assistance from U.S. intelligence.

The arrests were deeply symbolic—tangible signs of progress against the cartel. In reality, though, they just masked a much deeper problem. Del Toro Estrada's radio network was only the first step in the Zetas' information war. At the height of its power, the group developed a Stasi-like army of spies and integrated technology and social media into their operations. The result, ac-

ording to a report from the Mexican attorney general, was an intelligence network "without equal in the Americas." The Zetas monitored Twitter feeds, blogs, and Facebook accounts. They reportedly employed a team of computer hackers to track authorities with mapping software, and, according to one paper, 20 communications specialists to intercept phone calls. On the street, the cartel's informants included taxi drivers, taco vendors, shoe shiners—and often the police. In Veracruz, an entire department was dissolved after a commander was recorded ordering subordinates to serve as what the Mexican public, increasingly wary of its law enforcement, has come to call "polizetas".

According to a woman in Tamaulipas who had been involved with a midlevel member of the Zetas, the cartel was also sufficiently organized to divide busy urban areas like Nuevo Laredo into sectors made up of about a dozen streets, with each sector containing some 20 *halcones*—meaning hundreds of vigilant sentinels deployed across a given neighborhood. "They are usually hired for 10,000 pesos [about \$750] and provided two cellphones and a radio," she says. "They check who is walking down the street, and with whom. Usually it's the police, the military, and other gang members. You can see them sometimes at each corner, depending on the zone, even in the outskirts near the highways. It extends all over the city."

In just one location, a network of this size would generate hundreds if not thousands of texts, cellphone calls, and radio messages each day. Could a criminal organization be sophisticated enough to parse such a sea of data? Was there a roomful of bespectacled analysts somewhere, collecting and sifting through intelligence, then sending actionable leads up the chain of command? The answer, according to the former official familiar with Del Toro Estrada's case, is essentially yes. In Nuevo Laredo, he says, the Zetas had so deeply infiltrated the city police force that they were able to use the department's C4 office—Mexico's version of 911—to control its information network.

With the loss of its top leadership, the Zetas' power—just like that of its predecessor, the Gulf Cartel—seems to be waning. But profound success does not go unnoticed in any business, particularly one with billions of dollars at stake. The legacy of Del Toro Estrada's radio network and the Zetas' ruthless efficiency may have forever revolutionized the nature of cartel operations. In pioneering the use of new technologies and tactics—coordinated infantry-style attacks, hyperviolent "psy-ops" campaigns, sophisticated intelligence collection and communications—the Zetas created a new road map for criminal enterprise. To remain competitive, other cartels have created their own paramilitary units, and the Sinaloa Federation, Mexico's largest and most powerful drug-trafficking organization today, also reportedly has its own radio network. This is what some analysts have dubbed the "Zetanization" of Mexico. Cartel-deployed aerial drones and sophisticated data-mining software that tracks law-enforcement patterns and predicts ideal smuggling schedules and routes may not be far off. Such a nightmare scenario, if realized, will have started with humble beginnings: an anonymous shop owner armed with only a radio. 



PROP STYLING BY MEGUMI EMOTOH FOR ANDERSON HOPKINS

THE AIDS CURE

RESERVOIRS OF HIV HIDE DEEP
WITHIN THE BODY. SCIENTISTS ARE NOW CLOSING
IN ON METHODS TO WIPE THEM OUT.

BY APOORVA MANDAVILLI

IN 2007, a little-known German doctor applied to speak at a prestigious AIDS conference, claiming to have cured a single case of the disease. He described a 41-year-old man, dubbed the “Berlin patient,” who had had both AIDS and leukemia. The patient received a bone-marrow transplant from an HIV-resistant donor and no longer showed any sign of the virus.

Perhaps the conference organizers didn’t know what to

make of the case. They asked the doctor, Gero Huetter, to present the results on a poster instead of in a talk. So he did. The poster ended up hidden toward the back of a room.

“I ran into the poster by mistake. No one was paying attention to it; there was no buzz,” says Stephen Deeks, professor of medicine at the University of California at San Francisco. Deeks was blown away by the poster’s claim and recalls think-



Hematologist Gero Huetter cured a patient of both leukemia and AIDS by selecting a bone-marrow donor with a genetic mutation that blocks HIV from entering cells.

ing, “Why does no one seem to care about this remarkable case?” He moved on and didn’t discuss it with any of his colleagues.

Weeks later, Jeffrey Laurence, a researcher at Weill Cornell Medical College, stumbled across Huetter’s abstract in the conference program. As the first author of a seminal 1984 paper showing that HIV causes AIDS—a controversial idea at the time—Laurence was all too familiar with the deadening silence that can greet revolutionary discoveries. He wanted to believe Huetter’s claim, and so in his role as a consultant for AmfAR, The Foundation for AIDS Research, he organized a think tank of 12 people in September 2008.

Huetter was there, as were Deeks, Harvard University immunologist Judy Lieberman, and David Margolis, a leading AIDS researcher at the University of North Carolina. After scrutinizing the evidence, this jury of sorts unanimously decided that the Berlin patient, by then identified as Seattle native Timothy Ray Brown, was indeed cured of AIDS. “It was absolutely a turning point,” says Deeks.

Until then, the best scientists had hoped for was to control HIV infection by impeding the virus’s ability to reproduce. Brown’s case galvanized them into action. There are now dozens of labs investigating how to eliminate HIV from the body entirely. Several companies are developing techniques that mimic the genetic mutation that made Brown’s donor resistant to the virus; a handful are now in clinical trials. Funding agencies have changed course as well. In December, the National Institutes of Health (NIH) announced it would dedicate \$100 million over the next three years to accelerate such efforts.

“It’s a huge shift,” says Nobel Laureate David Baltimore, who is spearheading one of the new trials. “There is a real recognition that it’s possible that we can get a cure.”

Even among intractable diseases, AIDS is particularly challenging. It starts with HIV (human immunodeficiency virus), which embeds itself in a victim’s DNA. Once infected, cells cannot get rid of it, as they can most other viruses. What’s more, HIV targets cells in the immune system, converting them from disease fighters into mini factories, which then churn out more copies of the virus. Months or years later, the

number of immune cells drops so low that a person becomes susceptible to all sorts of opportunistic infections and develops AIDS (acquired immune deficiency syndrome).

If taken early enough, antiretroviral medication can prevent AIDS by keeping HIV levels in check, and there are more than 30 drugs designed to do that. Brown began taking antiretrovirals when he was diagnosed with HIV in 1995. Ten years later, he developed an unrelated case of acute myelogenous leukemia and deteriorated so rapidly that he soon needed a bone-marrow transplant. Bone marrow is the source of all of the body’s blood and immune cells, so a transplant essentially replaces the old immune system with a new one.

Huetter, Brown’s hematologist, recalled reading about a genetic mutation that prevents HIV from infiltrating cells. Called CCR5-delta32, it’s a mutant form of CCR5, a receptor that HIV needs to gain entry into one of its well-known targets: CD4+ T cells. The mutation occurs naturally in only about 1 percent of people, and Brown was lucky enough to find a matching bone-marrow donor who carried it.

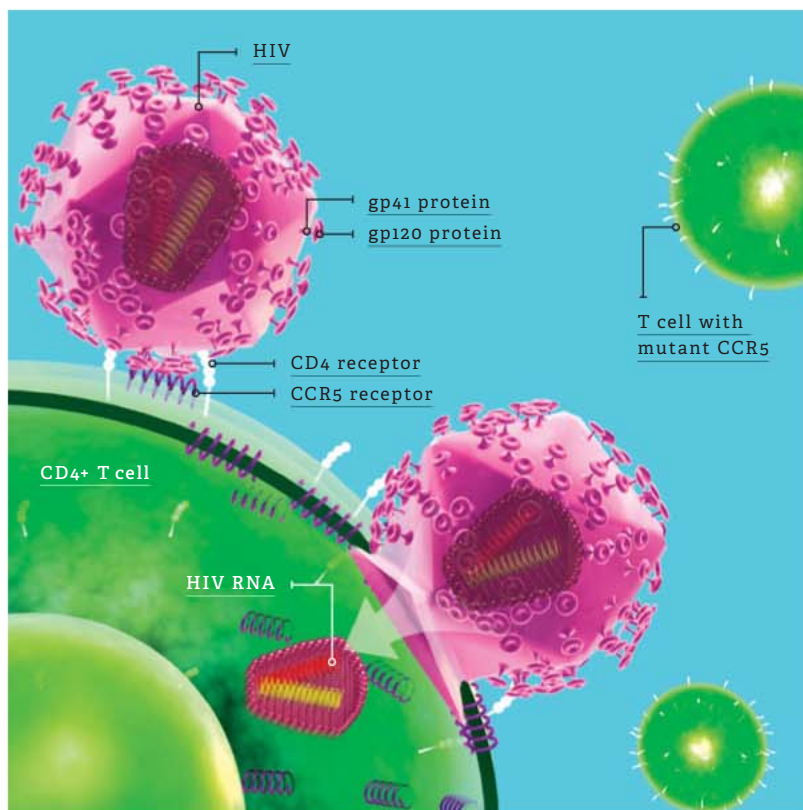
“I was told that if I got his stem cells, it would probably take care of my HIV,” Brown says. “I thought, ‘That would be nice,’ but I didn’t really believe it.”

Before his bone-marrow transplant on February 6, 2007, Brown underwent a punishing regimen of chemotherapy and total-body irradiation to wipe out his immune system. Two weeks later, he left the hospital with someone else’s. “That was the beginning of my new life,” he says.

Huetter’s original treatment plan called for Brown to continue taking antiretroviral drugs after the procedure. But Brown says his partner at the time, a massage therapist, had an “intuition” that the stem cells from the transplant wouldn’t reproduce properly if flooded with the chemicals. The transplant team was likewise reluctant to risk damaging the fragile new cells, says Huetter, and so Brown went drug-free. After the first few months, it slowly became clear that even without the medication, Brown showed no sign of HIV.

Other cases have since emerged that hold similarly tantalizing promise. Last March, a team of scientists reported that a three-year-old girl born with HIV in Mississippi remains free of the virus months after she stopped aggressive therapy. And French researchers published results showing that 14 people

✓ Deeks was blown away by the poster’s claim and recalls thinking, “Why does no one seem to care?”



HOW HIV INVADES CELLS—AND HOW TO STOP IT

1) HIV attacks immune cells that express a surface receptor called CD4. The best known is the CD4+ T cell. First, the gp120 portion of a protein protruding from the viral envelope, or virus's outer coat, latches onto CD4.

2) The binding triggers a structural change that exposes another viral protein, gp41. This protein docks with a second surface molecule called CCR5 (or for some cell types, another co-receptor called CXCR4), which enables HIV to penetrate the cell's membrane.

3) The virus then releases its genetic material, which embeds itself in the cell's DNA. The infected cell either begins churning out copies of HIV or silently waits to be activated.

4) Immune cells that carry a mutant form of CCR5 don't allow HIV to bind. Several research groups are trying to mimic this natural resistance by introducing mutant versions of CCR5 into HIV-infected people.

(now 19) who had been treated with antiretrovirals within 10 weeks of being infected have remained healthy for years after going off the drugs—more than 11 years in one instance.

Of these cases, only Brown has had a follow-up long and thorough enough—including brain, gut, colon, and lymph-node biopsies evaluated by multiple labs—to merit the unequivocal label of “cure.” But bone-marrow transplants are hardly an option for the 34 million people infected with HIV worldwide: They're arduous and highly risky procedures; up to one third of transplant recipients don't survive.

The transplants may not even work consistently. In July 2012, doctors announced that two men in Boston seemed HIV-free following bone-marrow transplants like Brown's. But unlike Brown, the men had remained on antiretroviral therapy after their procedures. When they stopped taking the drugs early last year, their infections came roaring back. It's not yet clear why—whether it's because their transplants didn't come from HIV-resistant donors, or because their pretransplant treatment didn't eliminate all of the infected immune cells, leaving some HIV hiding out in the body.

Still, Brown's case offers hope. It is evidence of something that until recently had been only a theory: that even after

many years of infection, when HIV has presumably wormed its way deep into a person's body, it is possible to eliminate it entirely, given the right approach.

HIV tests typically measure the amount of viral RNA in the blood. If you imagine blood vessels as highways, with some number of cars, or HIV-infected CD4+ T cells, traveling along them, the tests essentially try to extrapolate the number of cars on the road into the number of cars in the whole country.

The problem with this logic, says Mike McCune, professor of medicine at the University of California at San Francisco, is that there may be only a few cars on the highways because people have chosen not to drive, or gas stations have run out of fuel, or the factories that make the cars have been bombed.

In fact, in 1995, a team led by Robert Siliciano at Johns Hopkins University School of Medicine found that the vast majority of HIV hides silently in “resting” CD4+ T cells. When people go off therapy, the virus from this latent reservoir of infected cells rapidly resurges. In the analogy, this means that cars are



Timothy Ray Brown was officially declared cured of AIDS in 2009. Today, clinical trials are trying to replicate the success in other patients.

idling in garages, waiting for an opportune moment to pull out.

But even that is probably not the whole picture. For example, scientists have begun to realize that the reservoir contains other types of infected immune cells, such as dendritic cells, monocytes, and macrophages. In October, Siliciano and his colleagues reported in the journal *Cell* that the reservoir of resting CD4⁺ T cells alone may be up to 60 times larger than was previously thought.

Perhaps the biggest obstacle to curing AIDS, then, is this: No one knows what the reservoir is, where it is, or how to rouse the latent virus from it, much less how best to determine that it has been eradicated once it has been roused. These questions have prompted a tremendous amount of research, with scientists around the globe studying as many infected tissues as possible, both in people and animal models.

So far, one of the most popular strategies for obliterating the reservoir is the “shock and kill” approach. The goal is to somehow jump-start the dormant virus into becoming active, and then destroy the infected cells once they’re vulnerable—in other words, lure the cars out of the garages and onto the highways, and then blow them up.

Of the three AIDS research collaborations the NIH has recently funded, one focuses on this approach; academic researchers and the pharmaceutical giant Merck hold weekly calls to share unpublished results. “The idea is to find agents or small molecules or drugs that can reverse latency,” says Janet Siliciano, a virologist at Johns Hopkins University and a member of the group. “That’s a really, really hard problem. Right now there’s nothing out there that’s doing that.”

Brown’s case, she says, “created huge, huge excitement. It was a proof of principle that you could eliminate the reservoir if you could give someone a bone-marrow transplant.”

The Mississippi baby was given antiretroviral drugs starting at birth, and the most popular theory is that she was treated so early that the HIV reservoir never had a chance to fully form. The group of patients in France had also been treated soon after infection. As a result, their reservoirs may be so small that their immune systems can control the virus. The French researchers estimate that as many as 15 percent of patients who receive similarly early intervention may become “elite controllers”—a concept akin to that of cancer remission.

But Robert Siliciano cautions that these are unusual cases. “In most people, we’re going to have to deal with this reservoir somehow or other,” he says. “We’re not going to cure anybody unless we get rid of it.”

Scientists have known for many years that HIV’s dependence on the CCR5 receptor might prove to be its downfall. Brown’s case has given that hypothesis new momentum. Two California companies, Sangamo Biosciences Inc. and Calimmune, are using gene-therapy techniques to disable or delete CCR5.

In Calimmune’s trial, researchers take blood from an HIV-infected person, isolate stem cells, disable CCR5, and then transplant the stem cells back into that individual, where they will develop into new immune cells.

Theoretically, this approach has two advantages: The stem cells provide a steady stream of HIV-resistant immune cells, and altering a patient’s own stem cells rather than those from a donor circumvents the risk of rejection. The trial kicked off last summer, however, so it’s too soon to say if the strategy is as powerful in practice as it is in theory.

Sangamo’s approach is further along. It also modifies CCR5 but in T cells, which is easier to do. The company uses molecular scissors called zinc-finger nucleases to snip both copies of the CCR5 gene out of an HIV-infected individual’s T cells. Researchers then grow the modified T cells to large numbers and transplant them back into the patient.

In a trial of nine people, Sangamo found that a single infusion of the engineered T cells shrank the size of the reservoir in all of the participants three years later. In a separate trial of eight people, one person has maintained undetectable levels of the virus for 20 weeks (as of December) after stopping therapy.

“This is the first study to show a long-term durable increase in CD4 counts but a concomitant reduction in the reservoir,” says Geoff Nichol, Sangamo’s executive vice president of research and development.

Still, it’s way too early to say whether this effect will persist. Because T cells have a limited life span, it’s not clear how long a single infusion’s benefits will last. Sangamo is planning to

✓ The goal is to somehow jump-start the dormant virus and then destroy it once it’s vulnerable.



Experts seem to agree that any global strategy for eradicating HIV may need to combine a cure with a vaccine.

apply the same technology to stem cells, which might be able to provide an unending supply of HIV-resistant T cells.

A more interesting question is why this approach should have any effect on the latent reservoir—that is, why should an infusion of healthy immune cells decrease the number of cells that are already infected?

One controversial idea holds that the reservoir isn't entirely dormant. Imagine the reservoir as a sink half-filled with water. Each day, the water level is exactly the same as on the previous day. "But what you didn't realize is that the faucet's a little bit open, and the drain is also a little bit open," says Mario Stevenson, professor of medicine and chief of infectious diseases at the University of Miami. So even though the water level seems unchanged, there is fresh water in the sink. In the same way, the reservoir may be dynamic, with some cells getting infected and others dying every day.

In a person infused with the engineered T cells, the virus would gradually kill all infected cells without infiltrating new ones. In a sense, "you allow the infection to proceed untreated until the virus itself eliminates all of the nonengineered host cells," says Deeks. "It's a pure Darwinian experiment."

Even if Sangamo and Calimmune's approaches prove successful, and even if they turn out to have no serious side effects—and these are big ifs—they are too expensive and invasive to treat everyone infected with HIV. In fact, experts all seem to agree that any global strategy for eradicating HIV may need to combine a cure with a vaccine. After decades of failure with candidate vaccines, that field, too, has seen promising developments.

For example, after working with only a handful of neutralizing antibodies—immune molecules that can drive a vaccine—Dennis Burton and his colleagues at The Scripps Research Institute introduced two powerful new ones in 2009. That catalyzed an explosion of others. "Now there are literally hundreds," says Burton, a professor of immunology and microbial science.

Researchers have also created vaccines that spur healthy T cells to attack HIV-infected cells. They've shown dramatic protection in a monkey model of AIDS. And last October, scientists revealed the elusive structure of the protein protruding from HIV that the virus uses to latch onto CCR5. This protein is a target for antibodies elicited by vaccines. Put all of this

THE YOUTH CORPS

EACH YEAR, an estimated 250,000 children worldwide are born infected with HIV. What if hundreds, maybe even thousands, of them are now free of the virus and don't know it? This is the hope that the case of a baby in Mississippi offers.

The baby was born to an HIV-positive mother and received antiretroviral drugs within 30 hours. Normally, when a baby is diagnosed as HIV-positive, he or she begins treatment and continues it indefinitely. But the Mississippi baby stopped getting the drugs when she was about 15 months old. By the time she returned to the health care system, she had been off therapy for about a year. Instead of being desperately sick, she showed only a faint trace of HIV.

This discovery has led to speculation that the antiretroviral drugs killed off all of the virus before it had a chance to form a reservoir. To test whether that's plausible, some groups are embarking on ambitious

projects to treat infected newborns within a day or two of birth, discontinue treatment after one or two years, and then monitor them to see if the virus rebounds.

"Essentially the plan, based on the Mississippi baby, is going to be: Can you replicate this under controlled conditions in a larger number of people?" says Anthony Fauci, director of the National Institute of Allergy and Infectious Diseases, which is funding one such trial. If doctors follow enough of these children over time, they may eventually be able to verify that they are cured, Fauci says.

Other groups are looking to see whether HIV-positive teenagers who go on "drug holidays" and temporarily stop taking medication remain free of the virus. "The first step is remission. Maybe cure will be the next one," says Christine Rouzioux, a virologist at Necker Hospital and University of Paris Descartes in France. "It's the beginning of the story."

together, Burton says, and "you start to glimpse the possibility of controlling or even eradicating the virus."

In the meantime, Brown still holds the distinction of the first and only confirmed patient cured of AIDS. He has some survivor's guilt, he says, and is often called "lucky" by HIV-positive individuals. But his recovery was speckled with a series of nightmarish scenarios: At various points, he was incontinent and unable to walk, placed in an induced coma because of an acute sepsis infection, and so delirious he had to be admitted to a hospital for people with severe brain injuries.

Through all this, Huetter's team kept testing Brown and couldn't find any trace of HIV. But Brown says he didn't really believe his extraordinary situation until the *New England Journal of Medicine* published his case report in 2009. "Then I thought, 'Okay, the medical establishment is accepting that I'm cured,'" he recalls. "I guess I'm cured."





INVISIBLE WORLD

Noah Fierer wants to map the hidden universe of microbes—starting in your kitchen

By Joel Warner

Photograph by Sam Kaplan

On a recent morning, Noah Fierer, a professor of ecology and evolutionary biology at the University of Colorado, Boulder, found himself standing 1,000 feet above the farmland of eastern Colorado. He was perched near the pinnacle of the Boulder Atmospheric Observatory, a cellphone-tower-like spire built in 1977 to conduct climate and weather research. To reach the top, Fierer and his colleague Joanne Emerson had taken a five-minute ride in the tower's cramped catwalk 90 stories up. Dressed in hard hats and safety harnesses, the two leaned over to check a small device strapped to a latticework platform. The machine, which they'd installed several months earlier, sucked in air every night, filtered it, and stored the contents for col-

lection every two weeks. It was basically a vacuum cleaner but instead of hoovering up dirt, it captured microbes.

Microorganisms surround us. In the relatively desolate atmosphere at 1,000 feet, every cubic meter of air contains about a thousand microbes. Closer to the ground, that number skyrockets to 100,000, and on every square centimeter of human skin, it jumps to 10 million. A teaspoon of dirt contains 50 billion microbes, more than seven times the number of people on Earth. Yet despite such abundance, scientists know little about the microbial ecosystem. We understand less about the bugs in our home, for example, than the animals in the deepest ocean trenches. We know even less about their impact on us. How do microbes shape our daily lives—and how do we shape theirs? Do they trigger asthma



By sequencing microbial genomes, Noah Fierer has found an underlying order to the microbe communities that span the U.S.

and allergies—or help prevent them? It's as if we're living in an invisible world, and like the Victorian naturalists before him, Fierer is charting it.

One of the country's foremost microbial ecologists, Fierer collects and classifies microorganisms such as bacteria, archaea, fungi, and viruses. "I'm a natural historian of cooties," he says. Until a few years ago, microbial ecology was a relatively staid field. Because of the tiny size of the organisms involved and the inability to grow many of them in petri dishes, Fierer says, most microbiome studies were akin to surveying the biodiversity of the Amazonian rainforest and coming back with five species. Then came DNA sequencing. Fierer and others can now classify thousands of species quickly and easily and determine their functions. "It's fair to say we are entering a golden age of microbial ecology," he says.

In the past five years, Fierer has explored the microbial diversity of such environments as public restrooms, arm-pits, and caterpillar stomachs. Sometimes his findings shed light on the greater realm of microorganisms. At the Boulder Atmospheric Observatory tower, he's helping Emerson determine what kinds of creatures can survive in the air currents that blow in from California and beyond. Other times, his discoveries tell us about ourselves and how we unknowingly shape the microbial world. He's proved, for example, that people leave behind unique microbial fingerprints on surfaces like computer keyboards long after they've touched them, a fact that made it into a recent *CSI: Crime Scene Investigation* episode. (No one has used the technique in an actual investigation yet.)

Lately, Fierer has turned his attention to one of the richest and least understood

microbial environments: the American household. In 2011, he joined the Wild Life of Our Homes project, which was started by Rob Dunn, a biologist at North Carolina State University (and Fierer's co-author on studies that explored beetle bacteria and the organisms living in our belly buttons). The project aims to map the microbial biodiversity of homes across the U.S. "We really didn't know what to expect," Fierer says. As he and Dunn often point out in their research, there are more kinds of microbes in a

What's living with you?

Trillions of friends you never knew you had . . .

One morning about a year and a half ago, at my home in Brooklyn, New York, I woke up the usual way: My dog leapt into bed and plopped his face on

my pillow. That day, I wondered what came with him. Did living with an animal influence my apartment's microbial composition? To answer that question, I signed up for the Wild Life of Our Homes project, run by Rob Dunn at North Carolina State. Volunteers swab prescribed locations in their living spaces to collect microbial DNA, which is then sequenced to reveal which species appear where. Here's how I compare with 18 other people in the U.S.
BROOKE BOREL

SWAB LOCATIONS



KITCHEN COUNTER



FRONT DOOR, OUTSIDE



FRONT DOOR, INSIDE



PILLOW

There are more species of microbes in a typical home than there are species of birds on Earth.

typical home than there are species of birds on Earth. "It should be shocking to people that we live with thousands of species, some of which make us sick and some of which don't," Dunn says. "We have no idea what determines which ones live in your house, and for the most part, we have no idea which ones are beneficial or detrimental."

To change that, Dunn's citizen-science initiative at NC State advertised for volunteers. More than 1,400 people from all 50 states signed up. Each volunteer had to fill out a questionnaire about

his or her cleaning routines, pets and plants, and medical history, among other miscellanea. Participants then received basic swab kits, which they used to take samples from their kitchen counters, pillowcases, and the tops of interior and exterior doorsills. (In a 2011 pilot study of 40 homes in North Carolina, volunteers also swabbed toilet seats, door handles, TV screens, and other objects, but there was enough overlap among the microbial communities in those samples that the number of swab locations could be reduced.) The samples were then sent back

NERD BOX

A dot represents a single sample from a participant's house, colored by swab location. Samples that share more microbes appear closer together on the diagram. Our reporter sampled some extra locations, too [yellow circles].

OTHER PARTICIPANTS

My outer door
Not much evidence of soil or plants, even though it connects with the outside environment.

AVERAGE COUNTERTOP

Nearby park
Mostly microbes associated with soil, almost none of which ended up in my apartment.

My countertop
Normal, with high levels of plant microbes—likely from vegetables and other produce.

My tongue
Normal, but mixed with microbes more typically associated with dogs.

My inner door
Also low in plant and soil microbes, a pattern Dunn sees in urban dwellings like mine but not usually in rural or suburban homes.

AVERAGE DOOR, INSIDE

AVERAGE DOOR, OUTSIDE

My dog
A little bit of everything, though not as many soil microbes as found on dogs in rural areas.

My belly button
Filled with microbes associated with plants at levels so high Dunn says, "We haven't ever seen it."

My pillow
Among the "doggiest" pillows in the entire data set, says Dunn. Also present: bacteria from my skin and gut, oral bacteria from my drool, and vegetation, possibly from my oddly plantlike belly button.

AVERAGE PILLOW

Sole of my right foot
Mostly skin-related bacteria with, strangely, a hint of plant.

ILLUSTRATION BASED ON GRAPHIC BY AMY SAVAGE, YOURWILDLIFE.ORG.

to Fierer for DNA sequencing.

In Fierer's Boulder lab, researchers extracted the microbial DNA from the swabs using chemical solutions and centrifuges; then they chemically amplified and sequenced specific marker genes that could help identify species and their functions. In a matter of months, the team had compiled the largest data set on microbial ecology ever assembled. It contained hundreds of millions of DNA sequences and started yielding discoveries almost immediately. For example, researchers found about 3,500 bacterial species on interior door trims, meaning there are about 3,500 kinds of bacteria floating about in the average house—500 more than the study found deposited on exterior door trims.

As Fierer compared household data from different regions, he found that there were two main outdoor bacterial-and-

fungus-community types collected on doorsills, one predominately along the East Coast and in the Pacific Northwest, and the other prevailing everywhere else. "As soon as we saw it, we said, 'Holy crap, there is some structure here,'" Fierer says. What causes the different microbial clouds? Fierer thinks they could be linked to geographic patterns, including precipitation, soil pH levels, and forest cover. But only more research can say for sure.

Fierer could also see forensic applications for his work. "We may be able to demonstrate that we can use microbes found inside or outside homes to pinpoint where that home is located," he says. "It could even be used to determine where a criminal had been by looking at the microbes deposited on his or her clothes or deposited on surfaces in a car."

Data analysis on Wild Life of Our Homes continues, as do efforts to develop

digital interactive "report cards" that will allow the 1,400 volunteers to learn about the abundance and likely environmental sources of the various microbes that live on their pillowcases. In the meantime, Fierer is developing new projects. He'd like to investigate the links between skin microbes and body odor, and he champions the idea of protecting endangered microorganisms. "There's lots of literature on plant and animal conservation, but what's often left out is conserving microbes," he says.

As Fierer lists all the projects on his bucket list, it's hard not to picture a very different world from the one we know, one in which every surface has seething bacterial colonies, fungal deposits, and viral hoards. Yes, Fierer explains, we're all steeping in microbial soup—for better and worse. "Thankfully," he says, "I am not a hypochondriac." 🦋



DUST TO DUST

The desire to understand the formation of carbon particles in the outer space gave rise to the discovery of *nano-carbons*, which in turn spawned a fount of related research, Amiya Kumar Nandi and Raj Kishore Pandey from the chemical engineering and pilot plant division, High Energy Materials Research Laboratory (HEMRL), Defence Research and Development Organisation (DRDO), Pune, delve into the history of nano-carbons that was—literally—inspired by the universe, and the scientists responsible for it

Coal, graphite, and diamond are the allotropes of elemental carbon, and we are familiar with their various applications: Coal is known to us as a solid fuel. Graphite is used in pencils, batteries, microphones etc, and a diamond is precious jewelry.

STELLAR RESEARCH

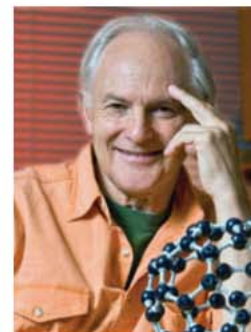
Scientists and astrophysicists have observed a carbon cloud in the outer space at the time of the extinguishing of a star in the form of a white dwarf. This carbon cloud has been named by them as the interstellar dust particle. Nearly three decades ago, in the 1980s, Dr. Harold Kroto (a chemistry professor from Sussex University, UK) was interested in carrying out research about the formation of carbon particles not unlike the interstellar dust, through a laboratory experiment. The project proposal was submitted to the UK academy of science. Unfortunately, it did not get financial approval. However, Prof. Kroto did not give up the research idea. He tried to convince few students to pursue this research work for their Ph.D program so that he could get some financial grant to procure required equipments /instruments to carry out the intended research. However, no student showed interest in the topic due to the lack of job prospects in the field. The good doctor, though, proved relentless in his pursuit. He approached Professor Richard Smalley, Rice University, USA, to collaborate on the research. Prof. Smalley, at the time, was occupied with research on the silicon semiconductor, and hence, did not show interest. He did, however, allow Kroto the use of his lab for 10 days.

Kroto borrowed money from his working wife, and crossed over to the States to make use of the opportunity. He prepared carbon vapor using laser light and took the spectroscopic data. However, he could not find any similarity in the spectral pattern of the produced carbon vapor with that obtained from the interstellar dust particles. He observed only a few lines in the spectra as compared to that obtained from the latter. This was possibly because the carbon particles produced in the lab must have contained a very high symmetry in their molecular structure. But what is that? What would that molecular structure have been?

A MEETING OF MINDS

On discussion, Prof. Smalley too seemed intrigued. He observed two types of carbon molecules in the produced carbon vapor. The type of carbon molecule which is present in a high quantity is made with 60 carbon atoms, and the other type of molecule is made with 70. However, arranging such large numbers of carbon atoms to get a highly symmetric molecular structure proved exceedingly difficult. Then, the two of them were joined by Prof. Curl for a brainstorming session one evening to conceive the probable molecular structure that could accommodate either 60 or 70 carbon atoms to obtain the symmetrical geometrical figure; but it was in vain.

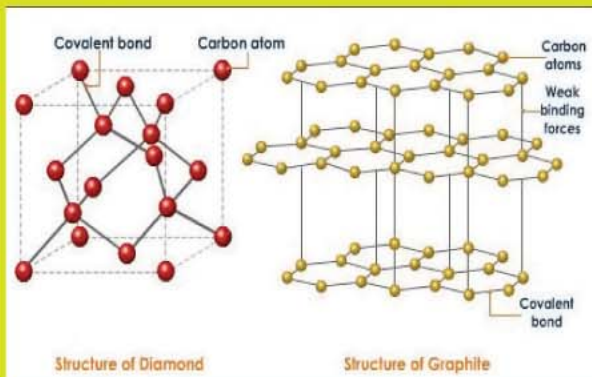
After returning home, Prof. Smalley shared this problem with his neighbor, a mathematician, and requested him to ponder the problem. Prof. Curl on the other hand, resorted to experience to find a solution. He recalled a trade fair he had attended in Montreal in 1967 and remembered a big dome-like pavilion he had seen there. He used that as inspiration to make a similar model structure, using a paper board to derive the probable geometrical structure for a molecule with 60 and 70 carbon atoms.



Prof. Harold Kroto

Prof. Kroto, meanwhile, had soccer on the mind, and went in search of a soccer ball to the local market. On not finding any (the game was not popular in the US at the time), he called his wife—it was after midnight in England and asked her to go to the cellar, and bring down the soccer ball stashed there. He then asked her to count the number of hexagons, pentagons, and the numbers of junction points (where three polygons are joined) in the ball. She did the deed and told Kroto that there were 20 hexagons, 12 pentagons, and 60 junction points in the ball.

Smalley, meanwhile, received a phone call from his mathematician neighbor the next morning, who mentioned the Euler formula used in geometry, and stated that, as per the formula, there must



Structural arrangement of carbon atoms in graphite and diamond



Buckminster Fuller's Biosphere – U.S. Pavilion at the 1967 World Exposition in Montreal

be 12 pentagons to accommodate 60 and 70 carbon atoms in a geometrical structure. However, the number of hexagons would change. The geometric structure would be like soccer and rugby balls, with 20 and 25 hexagons, respectively.

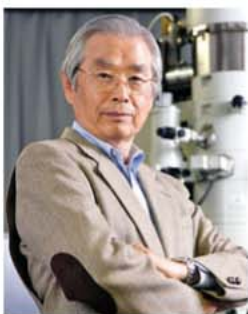
NAME CALLING

In the evening, the trio again sat together and shared their thoughts about the probable geometric structure of the molecule containing 60 carbon atoms. All of them concluded that it was a football. England-based Kroto wanted to name it “footballine”, given his fondness for the game, but the two other American scientists had the geodesic dome structure of the pavilion from the Montreal trade fair floating around in their mind, which had been constructed by famous architectural scientist, Buckminsterfuller. As the structure of the molecule containing 60 carbon atoms was similar to the dome, they named it the “Buckminsterfullerene”, which over the years, was simplified to “buckyball”.

This important discovery was the foundation of some tremendous strides in science and medicine in the coming years. With the help of Euler’s geometry, one can increase the number of hexagons and get bigger molecules containing more than 60 and 70 carbon atoms. It will increase to 72 and 84 carbon atoms for C_{60} and C_{70} respectively. All these molecules are a new allotrope of carbon i.e. “Fullerenes”, which is a black-colored powder highly soluble in benzene-like non-polar solvents. The three scientists went on to win the Nobel Prize in chemistry in 1996 for fullerenes 10 years after making the discovery: they had first prepared fullerenes in very minute quantities using laser light. Unless an easier method for the preparation of fullerenes was discovered, their research contribution would not get recognized. Later, Dr. Wolfgang Kratschmer and Dr. Donald Huffman invented a new methodology for its preparation.

CHAIN REACTION

Around the same time, Prof. Sumio Iijima was conducting research on the study of electron microscopic on the surface of carbon. As a result of the new discoveries by the three scientists, he became interested in doing research on the benzene insoluble part. He observed another appearance of carbon, where carbon atoms were arranged in the form of a chicken mesh. The hole of the mesh was hexagonal, and the carbon atoms were sitting at the junction points. But this mesh was not planar; rather, it was shaped like a cylinder, giving it a tube-like structure. The diameter of the tubes was less than 100 nm and they had more than one layer. Prof. Iijima named the tubes the multi-wall carbon nanotube (CNT), which then became the focus of scientific research. New discoveries were published one after the other, such as the single-wall CNT, double-wall CNT, CNT with one end closed, CNT with a Y-shaped end, CNT with different length and diame-



Prof. Sumio Iijima

ter, the folding and unfolding nature of CNT etc. CNTs are very good conductors of electricity, like metal, though some are non-conductors and others are semiconductors. For this reason, the use of CNTs will leave silicon behind in the field of electronics and IT.

FORM AND FUNCTION

CNT can be used for a variety of products and purposes. It can be used to make very light bulletproof vests, designed to absorb the energy of the bullet, and disperse the force of the bullet throughout the vest. This reduces the force of the bullet on one area, and prevents the bullet from penetrating the human body. However, in a regular vest (made with Kevlar polymer), the force of the bullet can still cause damage to the wearer by knocking them off their feet, bruising the skin, or causing severe injuries to internal organs. This is known as blunt force trauma. A superior bulletproof vest would be able to deflect most of the energy, as well as the bullet, upon impact.

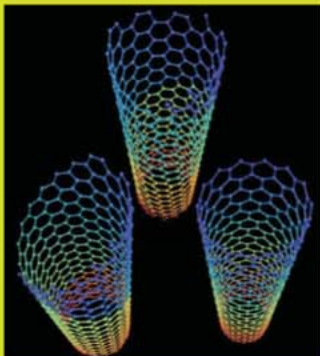
Carbon nanotubes are light, flexible, thermally stable, chemically inert, and extremely strong, making them ideal for bulletproof technology. In such a vest, millions of carbon nanotubes make up carbon nanofibers, which are woven together to create an extremely lightweight material. The carbon nanofibers are extremely good at absorbing energy, without getting permanently deformed, or failing. The high-elasticity module of CNTs is also a major reason why researchers are focusing on using it as bulletproof material. A team from the Centre for Advanced Materials Technology at the University of Sydney has recently developed a new material that is actually capable of rebounding the force of a bullet.

THE GREAT WALL

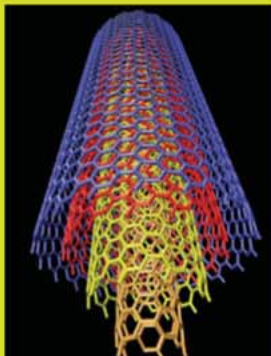
Cutting a single-wall CNT into smaller tubes and folding them will create the buckyball. Accordingly, CNTs are also called buckytube. A multi-wall CNT may be cut into smaller tubes, and the folding of smaller tubes will give an onion-like structure, called carbon nano-onion. Iijima was the first to prove the existence of carbon nano-onion.

The layered structure of graphite has been known for a long time. The carbon atoms are strongly bonded (covalently) in each layer. On the other hand, there is weak bonding (Van der Waals force) between two layers. However, as the millions of carbon atoms are joined together, the combined force is strong enough between two carbon layers. Is it possible to peel out a single carbon layer from graphite? In 2004, two scientists, Dr. Geim and Dr. Novoselov observed that it is possible to peel out a single carbon layer from graphite by rubbing the graphite on a scotch tape. These two physicists have been awarded Nobel Prize in 2010 for this invention.

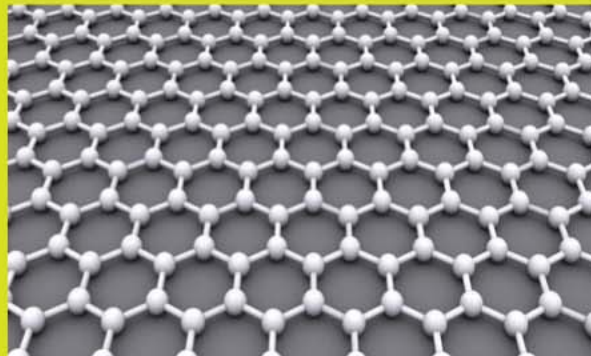
The single-layer graphite is called graphene. After its discovery, scientists were busy developing a correct methodology for large-scale production of graphene. They dug out old literature on methodology and recipe. It was found that Prof. Hanns-Peter Boehm first prepared graphene by using a chemical method in 1962. He analyzed it using an X-ray but could not conclusively prove the graphene structure of the synthesized product due to unavailability of electronic microscopy. However, till date, his recipe is found to be



Single-Wall Carbon nanotube (SWCNT); carbon atoms are sitting at the junction point



Multi-wall Carbon nanotube (MWCNT)



Illustrated structure of graphene

the best method for the preparation of graphene.

One particular area in which we will soon begin to see graphene used on a commercial scale is in optoelectronics; specifically touchscreens, liquid crystal displays (LCD), and organic light emitting diodes (OLEDs). For a material to be able to be used in optoelectronic applications, it must be able to transmit more than 90 percent light and also offer electrical conductive properties and therefore, a very low electrical resistance. Graphene is an almost completely transparent material and is able to optically transmit up to 97.7 percent of light. It is also highly conductive, and so it would work very well in optoelectronic applications such as LCD touchscreens for smartphones, tablets, desktop computers, and televisions. Thus, graphene will soon replace currently used material i.e. indium tin oxide (ITO).

NEW DIRECTIONS

CNT is like a narrow line—where there is length but width is negligible, thus making it one dimensional. However, buckyball and carbon nano-onion do not have any dimension and hence, they are zero dimensional. Graphene is two dimensional. The one-dimensional nanotube and two-dimensional graphene have made the silicon era of the electronic industry obsolete and initiated a new era of nanotechnology, whereas the zero-dimensional buckyball and the nano-onion have given a new direction in medical science.

Carbon is insoluble in water in all allotropic forms. But water is the only friendly medium in life. Thus, if we want to use carbon in medical science, it is essential to dissolve it in water. There is some progress in this field using the carbon dot and nano-onion. It has given a new direction to research i.e. wet nanotechnology. It was found feasible to wrap the carbon dots or nano-onions with a big organic molecule, which was highly soluble in water. Thus, the carbon sitting inside the core gets dissolved in water. However, this is not an easy method and very often, wrapping does not sustain long. An alternate methodology has been invented by introducing a water-soluble functional group on a carbon dot's surface. A deformation is created in the upper layer of a nano-onion by oxidation using nitric acid. The carbon is converted to carboxylate with the incorporation of two oxygen atoms. The presence of the carboxylate group on upper surface makes the carbon nano-onion highly soluble in water.

AN EYE FOR BENEFIT

We have been using nano-carbon for several centuries, in the form of kajal. Today, many people advocate that kajal is harmful for our eyes. This is not due to some organo-chemical reaction. These nano-carbons are very hard and sharp, which may be detrimental to the cell-wall of eye tissues. However, the same nano-carbons become soft when mixed with pure edible oil (coconut / mustard oil) and can be beneficial to eyes when applied carefully. They inhibit the growth of bacteria, and also, absorb chemicals which are harmful to eyes. American mothers give their baby colic-cum-water (a medicine made out of nano-carbons) to give babies relief from any stomach troubles.

In our country and elsewhere, after harvesting, we accumulate all the unwanted garbage of our field at one corner. We set fire to the pile allow it to char slowly (this process is called pyrolysis) to black powder i.e. bio-char, which contains nano-carbons. We do not allow for fast burning, as it leads to ash. The produced nano-carbons are beneficial to the crop. They retain micronutrients and water in the soil, and supply them to the crops gradually as per their need. Thus, it helps in reducing the consumption of fertilisers and water for cultivation.

MEDICINAL VALUE

Nano-onions are obtained by charring wood-dust. The upper layers of these nano-onions may be oxidized to the carboxylate group by nitric acid, resulting in soluble carbon. These nano-onions show different fluorescent properties depending on their size. Thus, they are used in medical science to analyze the inside of the human body. These nano-onions are also used to release cancer drugs selectively to the affected cells. In development biology (the subject to study the formation of the entire body of a living entity from a single cell), nano-onions have been used to study the entire life-cycle of a fly (*Drosophila Melanogaster*) with the help of fluorescent spectroscopy. These nano-onions are not harmful to living entities, and goes out of the body easily.

Carbon is the most widely used element in the universe, and we haven't even considered the enormous applications of carbon in the organic world where it combines with hydrogen, oxygen, and nitrogen. There wouldn't be any evolution of life on earth without carbon. . ♪

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Inside: A lethal crossbow built from trash. Turn Tyvek into an ultralight camping shelter. **Make stunning solargraphs with empty beer cans.** A real-life Ring of Power.

EDITED BY *Dave Mosher*

Manual



RECKLESS RIDE

A total of 256 pneumatic LEGO Technic pistons drive four radial engines, which turn the driveshaft and power the oversize rear tires. The car can reach 18 mph—but there are no brakes.

A LIFE-SIZE LEGO CAR YOU CAN ACTUALLY DRIVE



The Super Awesome Micro Project, a full-size car made of 500,000 LEGOs, sprung from an unlikely partnership between Romanian tinkerer Raul Oaida and Australian investor Steve Sammartino. The two met over Skype in 2012, and since then, Sammartino has helped Oaida raise money for his ambitious projects, including a jet-powered bicycle. After they saw a video of a Ferrari 599 GTB made of LEGOs, they set out to build something grander. "If you're going to make a LEGO car," Sammartino says, "you might as well make it a hot rod." Oaida spent 18 months constructing the compressed-air-powered vehicle and then shipped it to Australia for a test drive. The throttle and steering wheel snapped off, and a few high-pressure air hoses blew, scattering LEGOs everywhere. Oaida's quick fixes got it running again, but Sammartino thinks the seats still need work. "It might be the most uncomfortable car in automotive history," he says. **GREGORY MONE**

100,000

Parts in the compressed-air engine, which is made almost entirely from LEGOs

A HOMEMADE CROSSBOW DESIGNED TO IMPALE A CAR DOOR

Hackett is *Popular Science's* intrepid DIY columnist.

WARNING: Don't even think about attempting this project. You'll shoot your eye out, kid.

81.65
KG

Maximum draw weight of 16th-century longbows recovered from a shipwreck



English philosopher Thomas Hobbes believed that men living in anarchy would lead "solitary, poor, nasty, brutish, and short" lives. So as much as I'd enjoy rebuilding civilization from piles of trash after an apocalypse, I'd first worry about a way to send petrol-marauding punk rockers scrambling and make infectious zombies take a dirt nap.

A gun would do the trick. That is, until my ammunition ran out. Then I'd just have an awkward club. A crossbow, on the other hand, would mean business: The weapon has a fierce reputation for raw power and accuracy, and ammo can be made or retrieved with relative ease.

Going into this build, my crossbow knowledge was limited, but I knew I wanted something quiet, compact, and powerful enough to punch through our contemporary version of armor: a car. If my crossbow could shoot through a car door, I reasoned, then it would be a success.

A bowed weapon's strength is measured by its draw weight in pounds. The greater the pull on the prod (or bow), the more energy a bolt (or arrow) will deliver. I recovered a leaf spring from a truck chassis thinking it'd make a good prod. The power estimates I calculated seemed crazy, yet valid: Bending the 3/8-inch-thick bar just two inches could pull 227 kg. That kind of tension, coupled with a dense bolt, would create a force to be reckoned with.

I fashioned whatever I could find in my

227
KG

Calculated draw weight of Hackett's crossbow

31.8
KG

Typical draw weight that archers today can pull with a compound bow



Watch a video of Hackett testing his crossbow at popsci.com/diycrossbow

scrap bin into functional parts. I made a receiver to hold the trigger from an old metal pipe, and a winch from a threaded rod and hoisting hooks. An aircraft cable served as a string, a six-inch chunk of rebar as a bolt, and a discarded bike seat as a shoulder brace.

After days of tinkering, it was time to fire the crossbow—and that's when the leaf-spring prod revealed a disastrous flaw. Years of bouncing along roads created hidden stress fractures in the metal, which, part-way through cocking, burst into shrapnel. (Luckily, none of it hit me.) I plan to rebuild the crossbow with a new leaf spring, but the surest post-apocalypse plan is to raid a sporting-goods store for a bow and some arrows. I'd never give a medieval archer a run for his money, but at least I'd send the dimmest zombies lurching elsewhere. *PS*

Turn Empty Beer Cans into Sun-Tracking Cameras



In a world of digital cameras and instant gratification, photographer Justin Quinnell embraces pinhole photography, a technique hundreds of years old. He uses beer cans and photographic paper to record the gradual shift in the sun's path over the course of several months. Quinnell originally designed his simple beer-can solargraph camera for students at Falmouth University in England, but early experimentation quickly blossomed into a personal obsession. "The indestructibility of a pinhole camera opens up some fun possibilities," he says. "The only viewfinder you need is your imagination." Build and deploy your own by following these steps. **DAVE PROCHNOW**

MATERIALS:

- Empty 567- or 680-gram (20- or 20-oz) aluminum can
- 6-cm. disc (cut from black card stock)
- 25-by-7-cm. strip (cut from black card stock, with 1-cm. notches on one long side)
- Roll of black gaffer tape
- 8-by-5-in. sheet of semimatte photo paper (i.e., half of an 8-by-10-in. sheet)
- Plastic cable ties

Email your solargraph scans to manual@popsci.com

15 MIN.

Approximate time to build this project

Cost: Less than \$1 per photo

Difficulty:



APRIL 27, 2014

Worldwide

Pinhole Photography Day
(for details visit pinholeday.org)



INSTRUCTIONS:

1 Remove the can's top with a can opener, and poke the middle of its side with a pin. Next, cut out the disc and notched strip from the black card stock.

2 Wrap the strip around the can's base, and bend the notches inward at a 90-degree angle. Tape the disc on top of the notches to form a removable black lid.

3 Move everything into a darkened room. Turn on the red light to see, and insert 1/2 sheet of photo paper into the can facing the pinhole. Put tape over the pinhole.

4 Tape the lid over the can's open end, and secure it with gaffer tape. (Use plenty of tape to ensure the camera is light-tight and waterproof.)

WARNING: Wear protective gloves when cutting beer cans. Also mind the law; strapping up empty cans in public may be viewed as littering—or worse.

5 Take the project outside, aim the pinhole toward the southern sky, and vertically fasten the can to a signpost with cable ties. Uncover the pinhole.

6 Wait a month to a year (the longer the exposure, the more solar tracks appear). After the wait is over, cover the pinhole and take the camera indoors.

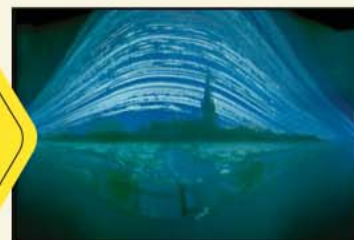
7 Remove the lid, and blow-dry the photo. Place it on a flatbed scanner, and make one—and only one—high-resolution scan. (Don't do a preview scan!)

8 Open the image, enhance its contrast (e.g., via "auto-equalize" or "auto-levels" commands), and invert the colors. Save the image to your computer.

TOOLS:

Can opener, pin, scissors, red light, blow-dryer, computer, flatbed scanner

RESULT
AFTER 6
MONTHS



Ask Anything

ANSWERS BY *Daniel Engber*



Wind chill? Heat index? Can't we combine them?

Short answer Scientists have—but they don't yet know if it will work.

A

More than 100 weather indices have been proposed over the past century in an effort to translate environmental conditions—how cold it is, how windy, how sunny, how wet—into felt experience and physiological risk. Many of these, like the wind chill and the heat index, focus on specific subsets of the variables in play. (The wind chill uses ambient temperature and wind speed; the heat index uses temperature and humidity.) But in the past few years, a group of 45 scientists from 23 countries, led by German meteorologist Gerd Jendritzky, devised what they call the Universal Thermal Climate Index (UTCI)—a simple, single-number

weather reading that could estimate how an average person would feel when faced with the elements.

Such an index would come in handy for researchers who wanted to compare weather-related stress and mortality across large areas. “If you want to look at the world weather map,” says George Havenith, co-chair of the UTCI collaboration and professor of environmental physiology at Loughborough University in Leicestershire, England, “then you would need a single index which covers both cold and warm.”

How does the UTCI work? It starts with four values measured locally: air temperature, wind speed, relative humidity, and solar radiation (i.e., how sunny it is outside). These values are then fed into a physiological model that takes into account the seasonal

clothing habits of an average European. The model estimates the stress put on the body—in terms of skin and core temperature, as well as sweating—and compares it with the strain brought on by a baseline condition. (In the model's baseline, there is no wind or sunshine, and 50 percent humidity.)

“I would not state that this is the perfect solution, but I think you could call it the current state of the art,” says Havenith. “What we need now is for people to start using the index and telling us what they think is wrong with it.” Given enough real-world testing and feedback, Havenith is convinced that the UTCI could be a useful, common language for talking about climate: “Wherever you would go in the world, you could see something on the weather report and understand what it means,” he says.

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